Universidade de Aveiro Departamento de Biologia
2005

Lúcia Maria Teixeira Pombo

Diversidade, dinâmica de populações e capacidade de produção ictiológica numa laguna costeira – a Ria de Aveiro

Diversity, population dynamics and fish production capacity in a coastal lagoon - the Ria de Aveiro

Universidade de Aveiro Departamento de Biologia
2005

Lúcia Maria Teixeira Pombo

Diversidade, dinâmica de populações e capacidade de produção ictiológica numa laguna costeira – a Ria de Aveiro

dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Biologia, realizada sob a orientação científica do Professor Doutor José Eduardo Rebelo, Professor Auxiliar do Departamento de Biologia da Universidade de Aveiro e do Professor Doutor Michael Elliott, Professor Catedrático do Department of Biological Sciences da University of Hull, Inglaterra.

o júri

Presidente:

Doutor Artur Manuel Soares da Silva
Professor Catedrático da Universidade de Aveiro

Vogais:

Doutor Jorge Guimarães da Costa Eiras
Professor Catedrático da Faculdade de Ciências da Universidade do Porto

Doutor José Pedro Andrade e Silva Andrade
Professor Catedrático da Faculdade de Ciências do Mar e do Ambiente da Universidade do Algarve

Doutor Amadeu Mortágua Velho da Maia Soares
Professor Catedrático da Universidade de Aveiro

Doutora Maria Ana Dias Monteiro Santos
Professora Associada com Agregação da Universidade de Aveiro

Doutor Leonel Serrano Gordo
Professor Auxiliar da Faculdade de Ciências da Universidade de Lisboa

Doutor José Eduardo da Silva Campos Rebelo
Professor Auxiliar da Universidade de Aveiro (Orientador)

Professor Michael Elliott
Full Professor, Department of Biological Sciences , University of Hull, Hull, HU6 7RX, Reino Unido (Co-orientador)

agradecimentos

Ao Professor Doutor José Eduardo Rebelo, agradeço a experiência e conhecimentos transmitidos no delineamento e orientação desta tese, o apoio prestado ao longo dos anos de trabalho em conjunto, pela amizade e também pelo incentivo na divulgação de trabalhos científicos.

Ao Professor Doutor Michael Elliott, expresso o meu reconhecimento pelos seus preciosos ensinamentos de carácter científico e também linguístico, pela disponibilidade em orientar, aconselhar e comentar os trabalhos desenvolvidos, apesar da distância física. *Thank you so much, Professor Elliott.*

Às minhas colegas de trabalho, Mestre Carla Lopes e Lic. Cláudia Dias, que se tornaram grandes amigas, com quem tive o prazer de compartilhar os longos dias de trabalho de amostragem, laboratorial, e também durante o tratamento dos dados, sempre com a maior dedicação e alegria contagiante, mesmo nos momentos mais difíceis.

Ao Sr. Aldiro, Técnico do Departamento de Biologia, que durante dois anos consecutivos, para esta tese, e mais um ano para o trabalho de Mestrado, revelou-se numa ajuda imprescindível, transformando o árduo trabalho de campo em momentos divertidos, e cuja amizade, empenho e dedicação levaram a bom termo as amostragens.

A todos os colegas e alunos, que participaram no trabalho de campo e de laboratório, também expresso o meu agradecimento, especialmente os alunos de Seminário em Vertebrados de 1999 e de 2000.

O trabalho foi realizado com recurso a apoio financeiro de uma bolsa de Doutoramento concedida, na primeira fase, pela Reitoria da Universidade de Aveiro e posteriormente pela Fundação para a Ciência e Tecnologia (FCT) e Fundo Social Europeu (FSE) no âmbito do III Quadro Comunitário de Apoio.

Finalmente agradeço à minha família, pais, irmãs e irmão, pelo apoio e valioso incentivo à execução deste trabalho. Ao Germano, a minha imensa gratidão pela ajuda, apoio incondicional e dedicação desde o início até ao final deste trabalho e finalmente à nossa filha, Sarinha, que agora tem doze meses e que me transmitiu uma energia renovada para pôr termo a este trabalho. A eles dedico esta dissertação.

resumo

A ictiofauna e as variáveis ambientais (temperatura, salinidade, oxigénio dissolvido, pH, turbidez e profundidade) foram amostradas mensalmente, na Ria de Aveiro, durante dois anos, entre Novembro de 1998 e Novembro de 2000, em 9 locais de amostragem, com a "chincha", uma rede de arrasto tradicionalmente usada na região.

Foram capturados 41 681 indivíduos de 61 espécies, com uma biomassa total de 222 quilogramas de peso fresco. As famílias mais abundantes foram Mugilidae, Atherinidae, Moronidae e Clupeidae, das quais seis espécies dominantes representaram mais de 74% da abundância total de peixes. A riqueza específica foi estatisticamente mais elevada em 1999 do que em 2000, com um pico no Verão em ambos os anos. A diversidade e a regularidade foram significativamente mais elevadas em 1999 do que em 2000 com picos na Primavera e no Outono em ambos os anos. Espacialmente, os dois índices foram mais elevados nas regiões intermédias da laguna do que na embocadura.

A temperatura foi o factor abiótico que mais influenciou a distribuição da abundância da comunidade íctica, a qual está mais relacionada com as migrações sazonais do que com as migrações espaciais. A salinidade foi o factor abiótico que mais influenciou a biomassa dos peixes, embora a temperatura também tivesse sido um factor importante a considerar.

Durante o séc. XX, ocorreram na laguna 92 espécies distintas pertencentes a 38 famílias de Agnatha, Chondrichthyes e Osteichthyes. Este ecossistema tem sido fortemente afectado por influências antropogénicas. Verificou-se que 13 espécies referidas no início do século não ocorrem actualmente.

A comunidade íctica é na maioria troficamente dependente de pequenos crustáceos pelágicos e bênticos e/ou de detritos, embora possam alimentar-se de forma oportunista de outras presas.

Atherina boyeri e *A. presbyter* evidenciaram comportamentos e características biológicas fortemente distintos, tais como a distribuição da frequência de comprimentos e a relação comprimento-peso dos peixes e dos otólitos. A sobreposição da dieta foi apenas notória nos indivíduos mais velhos. A combinação de estratégias alimentares diferentes em cada espécie indicou uma reduzida competição interespecífica.

A produção total anual de todas as espécies ícticas da laguna estimou-se em 90,3 t ou 2,1 $g.m^{-2}.ano^{-1}$ e 106,7 t ou 2,5 $g.m^{-2}.ano^{-1}$, no primeiro e segundo ano, respectivamente. *Sardina pilchardus* foi a espécie que mais contribuiu para a produção íctica total lagunar (estimou-se uma produção superior a 33% da produção íctica total). As capturas da pesca profissional atingiram cerca de 300 toneladas anuais, sendo três vezes superior à produção íctica lagunar estimada. Assim, é urgente uma gestão adequada das potencialidades naturais para assegurar a biodiversidade e recursos de pesca sustentáveis no futuro.

abstract

The ichthyofauna and environmental variables (temperature, salinity, dissolved oxygen, pH, turbidity and depth) were sampled monthly over a 2-year period, from November 1998 to November 2000, at 9 sites of Ria de Aveiro, with "chincha", a traditionally-used beach-seine-type net of the region.
A total of 41,681 individuals from 61 species were collected, with a total biomass of 222 Kg wet weight. Mugilidae, Atherinidae, Moronidae and Clupeidae were the most abundant families. Six species were dominant and represented more than 74% of the total fish abundance. Species richness was statistically higher in 1999 than in 2000, with a peak in summer in both years. Diversity and evenness were significantly higher in 1999 than in 2000 with peaks in spring and autumn in both years. Spatially, both indices were higher at the intermediate regions than at the lagoon mouth.
Temperature was found to be the most important abiotic factor affecting the abundance distribution of fish assemblage, which is more related to the seasonal migrations rather than to spatial migrations. Salinity was the most important abiotic factor affecting the fish biomass, with temperature also having a major influence.
During the 20th century, 92 distinct species and 38 families of Agnatha, Chondrichthyes and Osteichthyes occurred during the period. This ecosystem has been affected by large-scale anthropogenic influences. A total of 13 species that occurred in the beginning of the century have recently disappeared.
Fish is mostly dependent on small benthic and pelagic crustaceans and/or detritus, although they can feed opportunistically on other prey.
Atherina boyeri and *A. presbyter* showed behaviour and biological features markedly distinct as length frequency distribution, and fish and otolith length-weight relationships. The diet overlap was only evident on older individuals and the combination of different trophic strategies of each species indicates a reduced interspecific competition.
The total annual production of all fish species in the lagoon was calculated at 90.3 tonnes or 2.1 g m^{-2} $year^{-1}$ and 106.7 tonnes or 2.5 g m^{-2} $year^{-1}$ in the first and second year, respectively. *Sardina pilchardus* was considered the most important fish species with respect to fish production processes in the whole lagoon, accounting for > 33% of the total fish production in both years.
Professional fisheries reached about 300 tonnes in each year, which is three times higher than the estimated lagoon fish production. Thus, careful management of natural resources seems to be urgent to ensure the biodiversity and sustainable fish stocks in the future.

“Nature’s imagination is richer than our own”

Freeman Dyson

(Let’s have a good use of it)

CONTENTS

GENERAL INTRODUCTION

Lagoons and estuaries are difficult to define. The scientific need for classification and definition of habitats in general has developed from merely a scientific debate, such that workers understand the terms used in the field, to the politico-socio-management sphere (Elliott & McLusky, 2002). Terms considering water bodies are not precise and so confusion and disagreement arise when people discuss these subjects. In fact the term lagoon seems to be even more imprecise than estuary because the word estuary indicates salinity limits, whereas lagoons may vary from fresh to hypersaline waters. By using the term coastal lagoon we exclude the called lagoons of oceanic islands and atolls which are entirely different entities (Gunter, 1969). The concept of a pure coastal lagoon is one that lies paralleled to the shore such as the Ria de Aveiro.

In general, a lagoon is an area of shallow, coastal salt water, wholly or partially separated from the sea by sandbanks, shingle or, less frequently rocks (Brown *et al*., 1998). Additionally, lagoons retain a proportion of their sea water at low tide and may develop as brackish, fully saline, or hyper-saline water bodies (Elliott & Hemingway, 2002).

An estuary is a partially enclosed body of water formed where freshwater from rivers and streams flows into the ocean, mixing with the salty sea water (Gunter, 1969). Estuaries and the lands surrounding them are places of transition from land to sea, and from fresh to salt water. Although influenced by the tides, estuaries are protected from the full force of ocean waves, winds, and storms by the reefs, barrier islands, or fingers of land, mud, or sand that define an estuary's seaward boundary. Estuaries come in all shapes and sizes and go by many different names, often known as bays, lagoons, harbors, inlets, or sounds (Warler *et al*., 1996). Elliott & McLusky (2002) asked why so many scientists are so keen to extend the definition of “estuaries” in order to include their own local environment, why there is the need to derive alternative definitions or nomenclature, or whether it is possible to summarize a complex environment in a simple definition. They also concluded that physical definitions are apparently more objective rather than biological ones. This is particularly so given both the spatial and temporal variability but also the high mobility (often through seasonal

migrations) of many of the components (zooplankton, nekton, hyperbenthos, fishes, wading birds) (Elliott & McLusky, 2002).

Estuarine environments are among the most productive on earth, creating more organic matter each year than comparably-sized areas of forest, grassland, or agricultural land (Odum, 1997).

Estuarine coastal lagoons are topographic and hydrographic entities where mixing of fresh and salt water, sediments and nutrients take place under a set of dynamic condition, which we may call a flux equilibrium (Gunter, 1969). They are important as being marginal to the sea, they are fascinating and beautiful ecosystems distinct from all other places on earth and they are critical for the survival of many species. Tens of thousands of fish, birds, mammals, and other wildlife depend on estuarine habitats as places to live, feed, and reproduce (Odum, 1997).

Estuaries, in general, have long been regarded as important sites for fish, both as nursery and overwintering sites, giving them the nickname "nurseries of the sea", migration routes and areas which naturally support large numbers of fish (Haedrich, 1983). Hundreds of marine organisms, including most commercially valuable fish species, depend on estuaries at some point during their development.

The Ria de Aveiro is a typical estuarine coastal lagoon, sited on the west coast of Portugal, usually designated as a lagoon. It is the result of the lowering of sealevel, with the formation of coastal dunes since the 17th century. Connection to the sea was made artificially by a strip that has been maintained since 1808. The evolution process lasted for 800 years and occurred through the deposition of sand with the formation of coastal sand dunes and of a system of islands within the lagoon, this process was interrupted in the 18th century by human hand (Silva, 2000).

Based on the coastal dune between Carregal and Poço da Cruz (Mira), the Ria de Aveiro presents a maximum length of 45 km. Between the Bico de Muranzel and Fermelã its maximum width is 11 km, with an average width of 2 km. The lagoon area varies between 43 km^2 at low-tide and 47 km^2 at high-tide.

The lagoon receives its main fluvial inputs, from the north, the Vouga, Antuã and Fontão rivers and, from the south, the Boco river (Rebelo & Pombo, 2001).

The lagoon suffers a strong marine influence and is affected by fresh water inputs from the rivers that flow into it. The water salinity is similar to seawater near the mouth of the lagoon and decreases with distance inland. A well defined saline gradient is established and subject to seasonal variations (Silva, 2000). Due to the maritime influence, a diversity of biotopes have been formed in and around the lagoon (free water, islands with vegetation, beaches with silt and mud, marsh, salt works, agricultural fields and dunes) ecologically with high importance (Rebelo & Pombo, 2001).

Coastal lagoons are in a delicate natural balance, and therefore easily susceptible to detrimental environmental impact from pollution or by other human activities which, if uncontrolled, would exceed their carrying capacities and their abilities to sustain various kinds and levels of use. Coastal lagoons are integral parts of a larger and more complex system characterised by a highly dynamic biophysical environment (composed of terrestrial, aquatic and biological support systems which follow a complex array of natural processes) continuously undergoing change (Vallejo, 1982). Any planning scheme for their development and management should therefore be based on an integrated approach which considers the lagoon within the widest context of its surroundings areas as well as all the components and interactions between the subsystems. Thus, the geographical definition of the planning and management area should encompass the body of the lagoon, its catchment area, the region in which it exists, as well as the adjacent marine environment.

The Ria de Aveiro has provided a diversified economic base as food resources. Fishing and aquaculture, for example have constituted one of the oldest forms of coastal resource exploitation. The lagoon also provides recreational and aesthetic enjoyment, growing into the focus around which centres of population and industry have developed.

Some attempts have been made to measure certain aspects of the economic activity that depends on the Ria de Aveiro that also supports important public infrastructure, serving as harbors and ports vital for transportation, and industry.

Tourism, fisheries, and other commercial activities, however, thrive on the wealth of natural resources of the lagoon supply (AMRia, 2004).

Unfortunately, the increasing concentration of people is upsetting the natural balance of the lagoon and threatening their integrity. Channels have been dredged, marshes and tidal flats filled, waters polluted, and shorelines reconstructed to accommodate human housing, transportation, and agriculture needs (JAPA, 1993).

As the population grows, the demands imposed on the natural resources increase. So too does the importance of protecting these resources for all their natural, economic, and aesthetic values. It is the mission of the AMRia (Association of Municipal Districts of the Ria) to restore and protect the lagoon. This association was formed in 1989 and is composed of eleven Municipal districts involving the lagoon area, corresponding to an area under control of 1647 km^2. The main aims of the association are the promotion of the environmental quality of the lagoon and the elaboration of projects and studies that contribute for an economic, cultural and social development of the area (AMRia, 2004).

As long as the multiple uses on a lagoon are moderate, they may be accommodated. As demands intensify, strains appear. Conflicts inevitable and continually arise in the management of a lagoon as a multiple purpose resource. In resolving such conflicts, a number of management alternatives have to be considered and the likely effects of each of them have to be assessed. The prediction of beneficial and/or detrimental effects requires in-depth information and comprehensive understanding of the cause-effect relationships of three distinct but interacting elements: the natural ecosystem, the socio-economic and cultural base, and the regulatory and institutional infrastructure (Vallejo, 1982).

The integration of natural processes and human use patterns, which requires a set of continuing management and regulatory policies, is of vital importance for achieving the integrated management of both resources and used, as well as for anticipating the capacity of the area to absorb future demands (Vallejo, 1982).

There is no ideal formula that represents the management process of a coastal lagoon. As an integral part of the coastal zone, lagoons can be subject to

the broad coastal area management process, providing special consideration of the resource subsets (Vallejo, 1982).

In short, the Ria de Aveiro provides us with a whole suite of resources, benefits, and services. Some of these can be measured in money, others can not. This ecosystem is an irreplaceable natural resource that must be carefully managed. The success of the management depends on the knowledge of the lagoon, also on the biological aspects. Ecologists, especially ichthyologists, should have an important role in the understanding the fish diversity, dynamics of populations and in the assessment of fish production capacity of the lagoon, and therefore contribute to a possible integrated management that itself is not in their hands.

The concepts behind biological integrity and biological diversity are pivotal to strategies designed to sustain global resources (Lubchenco *et al*., 1991) and intimately dependent on knowledge of community structure. In order to determine if the perceived degradation of a system is real and to what degree it has occurred, it is necessary to understand natural and anthropogenic changes of the biological assemblages in that system over time and space (Matthews, 1998). However, multispecies assemblages vary greatly and are rarely quantified over both space and time (Matthews, 1998). From a basic ecological perspective, long-term monitoring of a lagoon fish assemblage is informative due to their highly dynamic or unpredictable environment. Have fish assemblages in these systems approached an equilibrium state, or are they continually developing (e.g. undergoing succession) or adapting to this new environment? Fish assemblages in estuaries and lagoons, which have a long history of co-occurrence, may have tightly linked associations among species (Carpenter *et al*., 1985). Additionally, we might expect different responses of individual species to local environment conditions.

Abiotic characteristics of each environment can be easily distinguished, while biotic differences, in spite of rather interesting, are more difficult to interpret. Thus, development of biotic assemblages in lagoons has to be well studied, as well as

fish species composition, species richness, diversity, and trophic interactions both upwards and downwards along food webs from the fishes.

In this study, the main aims were to investigate the fish communities of the Ria de Aveiro in terms of diversity and structure, population dynamics and the fish production capacity of the lagoon.

The objectives were to analyse the data for the fish communities, during a considering period of time (two years), collected at nine strategic stations of the lagoon. Furthermore, stomach analysis, age composition of several species, and the interpretation of the environmental factors completed the main proposed objectives. This work focuses not only on special/specific aspects of this ecosystem and their habitats, but also comparing it with other different estuaries and lagoons.

The hypotheses which were being answered and tested in the thesis were to test similarities and differences between different sites, months and years, and between them (month*site, month*year, site*year, and month*site*year) with respect to environmental factors and for the diversity indices (species richness, species diversity and evenness indices) for the whole fish community.

The thesis is subdivided in three different chapters: fish diversity and community structure, population dynamics, and assessment of fish production capacity.

The first investigation presented here began in 1996 using previous data made by the author, with repetition of the fishing effort in 1998/2000. The aim was to examine spatial and temporal changes in fish assemblage structure in the Ria de Aveiro over three years throughout their distribution, number of species, density and biomass. The environmental factors (temperature, salinity, dissolved oxygen, pH, turbidity and depth) were recorded and correlations between community structure and abiotic factors were identified.

Furthermore, the stability of the fish assemblage was assessed in terms of presence/absence of fish species, in response to human and natural changes of environmental factors. Previous works with fish assemblages in the lagoon

(Osório, 1912; Nobre *et al*., 1915; Arruda *et al*., 1988; Rebelo, 1992) in addition to recent investigations (all the papers presented in this work) has extended our knowledge of this variability and has been used extensively to monitor ecological conditions in the Ria de Aveiro estuarine lagoon. Thus, the first chapter examines differences in species associations between decades also using the data of previous investigations.

The second chapter, focusing the study on fish populations, considers the different uses of the lagoon by fish, as estuaries perform a crucial role in the life-cycle of many fish (Elliott & Hemingway, 2002). They provide a migratory route for anadromous and catadromous species and an environment in which the limited number of true estuarine teleosts spend the whole of their life cycle. The lagoon is colonised by few freshwater species while a large number of marine fish penetrate to the lagoon occasionally or looking for food. However, many marine teleosts enter and remain whithin the lagoon for a period of time, often in very large numbers and particularly during the early part of life (Blaber & Blaber, 1980; Potter *et al*., 1983; Whitfield, 1983; Elliott & Dewailly, 1995).

In addition of many aspects as dynamics of populations, migration and changes in a predictable way as abiotic factors change analysis, trophic dynamics have emerged from the vast data base that presently exists. Feeding habits of most species in the lagoon was at this time a lack of useful information for further studies in the lagoon. Diet composition of the ten species presented here will be a brief, general description of the methodology used to develop our data and examples of how trophic relationships may be coupled with distribution and standing stock data.

The quantification of predator-prey relationships in estuaries has often been the motivating force behind research in this field. Yet, rarely have such relationships been developed for fish and their prey from field experiments in this lagoon. However, competition for food or for habitats is an interesting issue to care about, especially the case of two species of the same genus and very similar morphologic characteristics, as the case of *Atherina boyeri* and *Atherina presbyter*.

As the species of the highest economic importance in the lagoon is already well studied - seabass (*Dicentrarchus labrax*) (Rebelo, 1993) - it was of value to

study two different populations of fish that in spite of their low economic importance in Portugal, have a high ecological importance. Atherinids are temporally and spatially very representative in the lagoon and they are included in the four most abundant species. Although both Atherinid species occur widely in large numbers, little attention has been paid to the biology of these species. Furthermore, there is confusion among investigators about the taxonomic status of the species as well as the number and delineation of species in the genus, which makes their study more interesting. In fact, some investigators proposed the synonymy of both species (Bamber & Henderson, 1985); however recent studies have demonstrated that differences are present between populations of *A. boyeri* and *A. presbyter*, consistent with the presence of two species (Creech, 1990, 1991, 1992). On the other hand, and on the basis of morphometric parameters, some others investigators have considered sub-species namely in *A. boyeri* as they considered polymorphism in the species (Marfin, 1982; Kartas & Trabelsi, 1990; Focant *et al*., 1992, 1999; Klossa-Kilia *et al*., 2002; Trabelsi *et al*., 2002a and b).

In the lagoon only two species of *Atherina* genus are known. *A. boyeri* is considered as a sedentary lagoon species (Marfin, 1981) spending its entire life in the lagoon. *A. presbyter* also often uses protected and shallow inshore waters as nursery areas and the transitory nature of estuaries, from a geological point of view, means that they could not be dependent on as a critical area for the survival of marine species. For the later two reasons, some workers have considered it more appropriate to refer to this category of fish as estuarine-opportunistic rather than estuarine-dependent (Lenaton & Potter, 1987).

Thus, the biological aspects and dynamics of abundant populations need to be examined, as they are mostly poorly understood. Ecology, age, growth rates and feeding preferences are also important studies in order to understand the life of the species and the biotic relationships between them. Age determination is rarely validated for fishes in general, however in this study the length-frequency analysis is used to validate the age estimation from otolith readings. These features also intend to be a useful contribution to the identification of Atherinids besides the wide used traditional taxonomy.

In other cases, in the Canary Islands, for example, *A. presbyter* is of great interest both as commercial target and as bait in the seasonal live-bait tuna fishery. This species is captured, near surface in the littoral zone, consistently year-round without significant differences in landings (Pajuelo & Lorenzo, 2000). In these cases, these studies also highly contribute to the management of the fishery exploiting stock.

The aim of this chapter was to study population dynamics. The objectives were to select ten species, according to their abundance, their ubiquity (presence in most sites) and their ecological behaviour in the lagoon. Thus, the two most abundant species of each ecological guild were selected, considering the total abundance of two years, except for the marine adventitious species and catadromous species due to the low abundance and due to the presence of a single species, respectively. *Atherina boyeri* and *A. presbyter* were studied in detail, namely its biology, age, growth and trophic ecology in order to find differences between these two species.

The productive capacity of fish habitat, the last issue of this research, is defined as: “The maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms upon which fish depend” (Department of Fisheries and Oceans, 1986). To make this definition operational for habitat managers, field measures of productive capacity need to be identified. Minns (1997) noted that the definition of productive capacity includes three key terms: production, maximum and natural. At a population level, techniques for measuring fish production rate (elaboration of fish biomass per unit area and per unit time) are described by Ricker (1975) and others, and fish production is routinely calculated for fisheries management (assessment of yield and harvest of exploited stocks).

In this work, production was established according to Ricker (1971), Bagenal (1978) and Crisp (1984) in Holme & McIntyre (1984) that defined production as the total elaboration of new body substance in a stock during a unit time, irrespective of whether or not it survives to the end of that time. Production depends on the time interval over which it is measured, the presence or absence of predators, and the growth and natural death rate of population. The combination of these factors

is very difficult to measure in situ and consequently production estimates are only approximate.

The production component of productive capacity is measurable in the field, although the time and effort required to collect the necessary population data are considerable.

At a fish community level, fish productivity was defined for an arbitrary area of habitat as “the sum of all production accrued by all stock during the time they spend any part of their life history in that area” (Minns, 1997). Production rate, or productivity, *per se* is most usually measured by habitat biologists (because of the time and cost); rather, alternatives are used such as fish biomass or yield, or the measure of surrogate habitat variables.

Prior to the present study, there was little knowledge about food web structure and productivity of important fish species for the lagoon; therefore, basic ecosystem research is a valid, indeed essential, activity in support of habitat questions.

The Ria de Aveiro maintains and supports a great variety of habitats leading to a high ecological and economical importance. The long-term and the artisian fisheries have high traditions in the lagoon area; however the coastal industrial fishery has been recently established. There is little information regarding the amount of captured fish in the Ria de Aveiro and this refers only to approximate annual weights extracted fish of the lagoon rounded, in 1956, to 2000 tonnes/year. Later on, between 1962 and 1977, the volume decreased to 500 tonnes/year due to heavy pollution in the waters. More recently, between 1989 and 1990, this decrease was confirmed as 400 tonnes of fish per year in the Ria de Aveiro (Reis, 1993).

More recent data available in Docapesca has recorded the evolution of fishing along the years with the respect to the Aveiro region, thus allowing the differentiation between the fish caught in the Ria and in the sea. Thus, considering that approximately only 5% of total catches corresponded to the caught fish in the Ria de Aveiro, the data indicate that 397 tonnes of fish in 1998, 292 tonnes in 1999, 291 tonnes in 2000, and 292 tonnes in 2001 were caught in the lagoon. In addition to the artisian catches in the lagoon, it is of note that the recreational

fishery (for which 6940 boats were recorded in the Aveiro Port) is also important in the total catches of the lagoon, although its values were impossible to be measured. As this fact comprises a considerable importance of Ria de Aveiro to the local economy, it is important to know whether those catches are above or below the productive fish capacity of the lagoon, to know if the lagoon will be in risk in the near future. It is considering those important questions that the assessment of the fish productive capacity will be held in the third chapter of this work.

In summary, this PhD thesis is a compilation of seven papers published or submitted for publishing organised in three different parts. The first chapter quantitatively characterises the fish assemblages occupying the Ria de Aveiro estuarine lagoon and detects significant spatial and temporal differences in those assemblages and also determines long-time fish changes within one century. The second chapter discusses the main ecologically important populations, aiming to study dynamics of that populations, in particular two populations of Atherinids, in terms of age, ecology, growth and trophic preferences. Finally, the third chapter focusses on the assessment of fish productive capacity of the ecosystem in order to provide information for monitoring the status of this estuarine lagoon as a start to a proper and sustained management.

The main aims and objectives of each chapter are well described in the introduction of the chapter. Discussions are provided at the end of each chapter followed by the references. A general introduction and a general discussion intend to integrate all the issues of the particular papers and chapters and finnaly global conclusions are addressed.

CHAPTER I – Fish Diversity and Community Structure

Introduction

Diversity, community structure and stability are concepts that have been discussed by ecologists for a long time. The stability of an ecological system has been considered as a function of the number of species and the level of interaction between them (Elton, 1958), i.e., the community structure. With the concept of community stability, ecologists are required to analyse the magnitude and mechanisms of ecosystem disturbance (Begon *et al*., 1990). Some ecologists (Elton, 1958) suggested that diversity stabilises the communities while others (Pielou, 1975; May, 1976; Zaret, 1982) support that in contrast it makes them dynamically fragile. It is interesting to perceive that the different trends are right in part, although it seems clear that a basic condition for continuity of the communities' existence is a relatively stable environmental history for making possible the establishment of homeostatic mechanisms (Alcolado, 1996). According to Pecenko (1982), diversity, as a property of community, is the reflex of its structure and complexity, but not necessarily its stability. The diversity-stability relationship has no direct cause-effect. The ecological complexity represents the biological diversity in a large sense, including not only the species diversity but also the ecosystem diversity, as well as the genetic diversity of populations (Sala, 1994).

Species diversity is an important concept that reduces the information about species-abundance relationship in an assemblage of organisms to a single number that can be compared with other values in space and time. Diversity can be computed in a number of ways, but measures based on a probability distribution have advantages over common distribution-free indices (Shepard, 1984). Specifically, they avoid ambiguity associated with confounding effects of richness and evenness; are more interpretable because use of the distribution requires fewer restrictive assumptions than that for a distribution-free index; and provide distribution-based statistics that can be used to compare species-abundance patterns in time and space.

The complexity of an ecosystem is an expression of the existing species, their abundance and their interactions and how they integrate themselves in time

and space. Orians (1975) suggests that the behaviour of an ecosystem in response to environmental disturbances depends greatly of the adaptive characteristics of the resident organisms. Thus, it can be said that a coastal lagoon is comparably less diverse and less constant but more resistant and more elastic, and also dynamically stronger than a reef of high diversity (Alcolado, 1996).

Traditionally lagoons and estuaries have been described as being hostile, demanding or physically stressed when compared to more stable environments, such as the deep sea. Hence, organisms in lagoons and estuaries would be expected to demonstrate a wide array of adaptations to the numerous physical, chemical, and biological factors which comprise this ecologically interesting ecosystem (Vernberg, 1982).

Lagoons and estuaries are also characterised by a relatively low ichthyofaunal diversity but high abundance of individual taxa, most of which exhibit wide tolerance limits to the fluctuating conditions found in these systems (Whitfield, 1994). Furthermore, fish assemblages provide good indicators of ecosystem structure and health (Karr, 1981; Whitfield & Elliott, 2002) and are often the object of management concerns. Considerable effort has been expended in assessing ecosystems health and studying the factors structuring fish assemblages in aquatic systems (McKenna, 2001).

Although biologists frequently study the influence of one or few environmental factors at a time, it is of note that many factors may vary independently or in concert to affect an organism and the entire environmental complex. Beyond abiotic factors, also biotic factors, such as competition or predation, affect fish assemblages and their variability. In addition to contemporary conditions and processes, historical events and regional species richness have often influenced to local fish assemblage structure (McKenna, 2001).

Long-term monitoring of a species assemblage can provide valuable information on the basic ecological forces that structure biotic communities (Gido *et al*., 2000) and provide baselines to test the effects of natural and anthropogenic disturbances (Elliott, 1990).

Long-term studies are also necessary to establish a baseline for management recommendations and to predict future yield of these fisheries. The proper management of estuaries and lagoons is of global importance because they serve as nurseries for many marine and estuarine dependent species (Rogers *et al*., 1984 *in* Rakocinski *et al*., 1996; Elliott & Hemingway, 2002) behind of their economic importance for recreational, commercial and subsistence purposes (Gido *et al*., 2000).

This chapter outlines the way in which fish population dynamics are linked to their habitat. Specifying these linkages provides the conceptual basis for habitat-based fish population models that are needed by fishery managers and researchers to predict the effects of habitat changes on fish populations. Before doing this, it is of value to examine how fish habitat has been defined, and consider how habitat and population dynamics are associated under these definitions. A common paradigm of fish habitat focuses on the physical and chemical characteristics of the environment, explicitly excluding biological factors as part of "habitat". For example, "habitat for fish" is a place – or for migratory fishes, a set of places – in which a fish, a fish population or a fish assemblage can find the physical and chemical features needed for life, such as suitable water quality, migration routes, spawning grounds, feeding sites, resting sites, and shelter from enemies and adverse weather (Hayes *et al*., 1996). Although food, predators and competitors *are not* habitat, proper places in which to seek food, escape predators, and contend with competitors *are* part of habitat, and a suitable ecosystem for fish includes habitat for these other organisms, as well (Orth & White, 1993).

Some other questions come out with this study: Have fish assemblages in this system approached an equilibrium state, or are they continually developing (e.g., undergoing succession) or adapting to new environments? Fishes may be continually challenged by changes in their environment or interactions with introduced species. Additionally, we might expect different responses of individual species to local environment conditions. For example, migrant species may be less suited to the local climate than resident species of the lagoon (Gido *et al*., 2000).

According to Chaplin *et al*., (1995) the factors that govern the impact of loss or introduction of one species in an ecosystem are:

1. the number of species ecologically similar in the ecosystem, i.e., the redundancy of each functional groups. This concept is based on the fact that each species has a particular response/tolerance to environmental changes, so a high climatic change would be unlikely to eliminate all the species, with new colonisers migrating to replace those lost. This is some kind of "life insurance" or survival of the community;

2. the influence of some species in the ecosystem by qualitative and quantitative effects (substitution capacity). The loss of a non keystone species will produce a minor effect in the community as it can be substituted by other species. Quantitative effects can include on the productivity or on the amount of available nutrients. These effects can be determined by differences in the rate of relative growth that influence the rate of food resources.

Some published studies address changes in fish assemblages in estuaries and lagoons (Blaber *et al*., 1989; Elliott & Taylor, 1989; Loneragan & Potter, 1990; Blaber, 1991; Pomfret *et al*., 1991; Elliott & Dewailly, 1995; Tremain & Adams, 1995; Hayes *et al*., 1996; Potter *et al*., 1997; Young *et al*., 1997), although very little attention has been paid to the several factors that may adversely affect over time the fish assemblages, such as sedimentation, erosion of shorelines, dredging, water dynamics, pollution, fisheries, among many others (Beverlhimer & Adams, 1996).

Previous works (Arruda *et al*., 1988; Rebelo, 1992; Pombo & Rebelo, 2002; and Pombo *et al*., 2002) have examined differences in species assemblages between decades. In addition, the pioneer works at the beginning of the century (Osório, 1912; and Nobre *et al*., 1915) made possible the analysis of species diversity in a long time variation using data recorded during the past 100 years.

The comparison among these different works in different times needed to be compared in order to analyse the evolution of the system in relation to the species composition and, if possible, in relation to physical and chemical variation. These studies are also indicators of the state of the health and the biological integrity of the lagoon.

This chapter aims to examine changes in fish community structure in Ria de Aveiro estuarine lagoon over three years investigated by the authors and comparing previous works made in the lagoon with the recent research during the twentieth century. Furthermore it was assessed the stability of the fish community in response to disturbances caused by weather conditions and the influence of abiotic factors.

The objectives included long-term changes within the typical estuarine coastal lagoon, Ria de Aveiro, which have been examined since 1912 to quantify variations in species richness, fish diversity and evenness and evaluation of the resistance and resilience of the fish community to abiotic and also biotic disturbances. The same strategically sampling sites was used based on intensive monthly sampling with the same type of net and under the same conditions (at low tide, during the five days of the new moon at adjacent, non-overlapping areas) as described in the following papers.

The hypotheses which intended to be answered in this chapter were to test significant differences among the abiotic parameters including months, sites and years, and interaction between them. The same tests were used for the diversity indices. Furthermore, multiple paired tests were used to determine if whether any year was different to any other year according to each group of guilds.

The first paper was designed to quantitatively characterise the fish assemblages occupying the estuarine lagoon, Ria de Aveiro, and to firstly determine the state of the art of the fish structure and the use and ecological importance of the lagoon for its various fish populations. The second paper intended to determine significant spatial and temporal differences in fish assemblages and to identify correlations between distinct fish assemblages and abiotic conditions and identify factors responsible for maintaining structure of the fish assemblages. Finally, the third paper analysed a long-time variation of fish diversity considering the previous works and the recent studies made by the authors, during the last century. The results of these works provide vital information for monitoring the status of this system.

Spatial and Temporal Organization of a Coastal Lagoon Fish Community – Ria de Aveiro, Portugal

Pombo, L. & Rebelo, J.E. 2002.

Cybium, the European Journal of Ichthyology 26(3): 185-196

Spatial and Temporal Organization of a Coastal Lagoon Fish Community – Ria de Aveiro, Portugal

Abstract

The fish community and its spatial and temporal organization were studied in the Ria de Aveiro. This lagoon system (43 km^2 in area), has both marine and fluvial influences and is located between 40º 30' - 40º 52'N and 8º35' - 8º 47'W on the central coast of Portugal. The ichthyofauna was sampled monthly, from December 1996 to November 1997, at nine selected stations, with "chincha", a traditionally-used beach-seine-type net of the region. A total of 14,598 specimens representing 43 species from 21 families were caught. The abiotic parameters (temperature, salinity and dissolved oxygen) showed significant seasonal variations, although only salinity and transparency showed statistically significant trends among sampling stations. The diversity and evenness were greater at the borders of the lagoon. The species richness, diversity and evenness peaked in mid-Summer. Marine seasonal migrant species were the most numerous, and the marine juvenile and estuarine resident categories had the highest number of species. Species number and diversity of the ecological guilds showed some spatio-temporal patterns due to some particular dominant species. Mugilidae, Atherinidae, Moronidae and Clupeidae were the most abundant families. Six species were dominant and represented more than 74% of the total fish abundance, although they did not occur over the whole lagoon area or during the whole sampling period. The study concludes that the fish community of the Ria de Aveiro has well-defined seasonal and spatial patterns.

Keywords: fish, diversity, evenness, ecological guilds, Ria de Aveiro.

Introduction

The Ria de Aveiro, on the west coast of Portugal is a typical estuarine coastal lagoon. The particular abiotic attributes of this system - shallowness, high turbidity, nature of the substrate, temperature, salinity and oxygen - associated with its high

biotic productivity, offer excellent conditions for colonisation by many species, especially teleosts (Potter *et al*., 1990; Rebelo, 1992).

This coastal lagoon is economically important because of its fisheries, industry, agriculture, sea farming, tourism and, more recently, aquaculture. With a good communication with the sea, that guarantees a seasonal fish recruitment, the lagoon is an area of considerable fish exploitation (commercial and recreational). Previous ichthyological studies in the Ria de Aveiro (Osório, 1912; Nobre *et al*., 1915; Arruda *et al*., 1988; Rebelo, 1992) contributed to the knowledge of the dynamics and evolution of the fish populations inside this lagoon and its relationship with the adjacent ocean.

This paper describes the spatial and temporal patterns of the fish community, in terms of ecological categories throughout their distribution, number of species, density and biomass. This allows an interpretation of the use and ecological importance of the lagoon for its various fish populations.

Study Area

The morphology of the Ria de Aveiro (Fig. 1) shows relatively recent development starting in the tenth century, and in 1808 the connection with the sea (470 m width) was first stabilized by man. The topography and physical characteristics of the Ria de Aveiro were described by Barrosa (1980). The area is 42 km^2 at low tide and 47 km^2 at high tide. The depth at low tide is only 1 m over most of the lagoon, but can reach 10 m near the mouth and in the navigation channels. Tidal action mixes freshwater with seawater entering from the mouth. The tidal input is approximately between 25 and 90x10^6 m^3 for

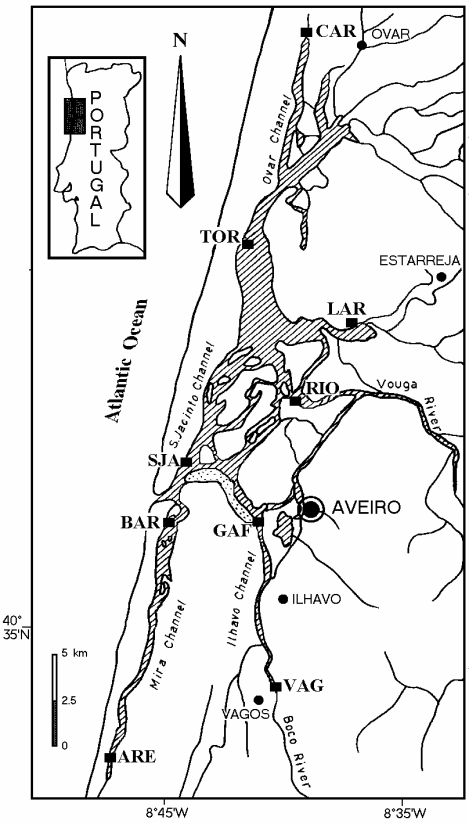

Fig. 1 - Map of the Ria de Aveiro lagoon showing sampling stations: ARE= Areão, BAR= Barra, CAR= Carregal, GAF= Gafanha, LAR= Laranjo, RIO= Rio Novo de Príncipe, SJA= São Jacinto, TOR= Torreira, VAG= Vagos.

tidal amplitudes of 1 and 3 m respectively. Currents produced by this tidal action are significant only in the mouth, the central part of the main channels and a few other restricted areas. There is a delay of 6 hours in the times of high and low water between the mouth and the extreme margins of the lagoon.

The nature of the sediments is extremely variable, particularly the granulometry. Its composition varies between 20 to 90% of sand, 10 to 80% of silt and 0 to 30% of clay. In the north the sediments are finer but become coarser with progression to the south (Borrego *et al*., 1994).

The lagoon receives considerable flows of raw and treated wastewater. Three main pollution types are apparent: organic and chemical pollution from paper-pulp factories (in the rivers of Vouga and Caima); chemical pollution, particularly mercury, from the industrial area of Estarreja (in Laranjo area); and microbial contaminants from the urban sewage effluent and cattle raising areas (Ílhavo channel, Vouga river and Ovar channel) (Lima, 1986; Lucas *et al*., 1986; Borrego *et al*., 1994).

Material and Methods

Sampling Period and Study Sites

Fish were collected monthly, from December 1996 to November 1997, at nine selected stations (Fig. 1): near the mouth of the lagoon (BAR, GAF and SJA); at the edges of the main channels (ARE, CAR and VAG); in the main freshwater area, highly organically enriched (RIO); in the area showing the highest levels of industrial pollution (LAR), and approximately in the middle of the longest channel (TOR).

Sampling Methods

Samples were monthly taken in triplicate at low tide with a “chincha”, a traditional beach-seine (Fig. 2). Stretched mesh sizes in the chincha were 19 mm at the wings, 17 mm at the cod mouth, 16 mm at the cod sleeve, and 10 mm at the cod-end piece.

Abiotic parameters (temperature and dissolved oxygen) were recorded with an oxygen meter (CONSORT Z621), salinity was recorded with a refractometer

(ATAGO) and water transparency was estimated based on turbidity and Secchi depth, according to Yáñez-Arancibia *et al*., 1983 (Rebelo, 1992).

Fishes were preserved by freezing. At the laboratory each specimen was identified, according to the taxonomic keys of Bauchot and Pras (1987) and Whitehead *et al*. (1986), measured (total length), and weighed (total weight).

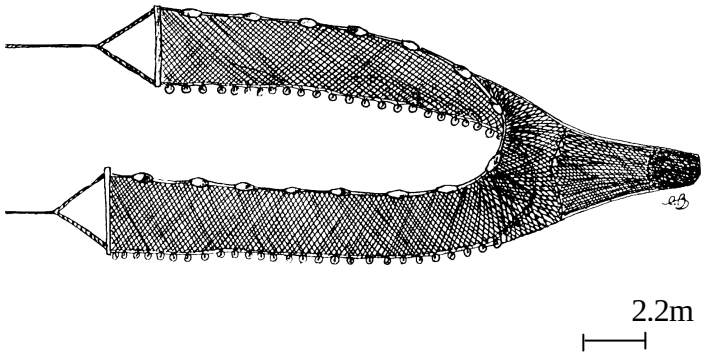

Fig. 2 - Perspective drawing of the “chincha”, showing the conical cod-end in the centre of the net. Scale bar= 1:220 cm.

Data Analysis

Two-way ANOVA without replication (Zar, 1984; Sokal & Rohlf, 1995) was carried out to test significant differences among the abiotic parameters between stations and months. Homogeneity of variances was tested using the Fmax test (Zar, 1984; Sokal & Rohlf, 1995).

The assemblage structure and dynamics were calculated according to the following parameters:

a) species richness, Margalef index (R) (Margalef, 1958 *in* Ludwig and Reynolds, 1988; Legendre & Legendre, 1984b), which refers to a total number of species that compose a community, and is described by:

$R = \frac{S-1}{\ln(n)}$, with *S* the total number of species and *n* the total number of individuals observed in a sample.

b) species diversity index (N2), (Hill, 1973) is defined by the inverse of the Simpson index (λ), $N2 = \frac{1}{l}$, where $l = \sum_{i=1}^{S}\left(\frac{n_i}{N}\right), i = 1,2,3,...,S$ with n_i the number of specimens of *i* species and *N* the total number of individuals of the *S* species of a population.

c) evenness index, (E) (Ludwig & Reynolds, 1988) which varies between 0 and 1, $E = \frac{(1/l)-1}{e^{H'}-1} = \frac{N2-1}{N1-1}$, λ is the Simpson index, *H'* is the Shannon-Wiener index and *N2* and *N1* are the diversity numbers (Hill, 1973), where $N1 = e^{H'}$ and $H' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right).\ln\left(\frac{n_i}{n}\right)\right], i = 1,2,3,...,S$ with n_i the abundance of the *i* species, and *n* the abundance of all species.

In order to understand the use and importance of the lagoon for fish, species were grouped, using the method of Elliott & Dewailly (1995). Six categories were defined according to their biology and behaviour and using background information for the lagoon (Osório, 1912; Nobre *et al*., 1915; Arruda *et al*., 1988; Rebelo, 1992). The categories were *i*) estuarine resident species (ER), which spend their entire lives in the estuary; *ii*) marine adventitious visitors (MA), which occur irregularly in the estuary but have no apparent estuarine requirements; *iii*) diadromous (catadromous or anadromous) (CA) migrant species, which use the estuary to pass between salt and fresh waters for spawning and feeding; *iv*) marine seasonal migrant species (MS), which make regular seasonal visits to the estuary usually as adults; *v*) marine juvenile migrant species (MJ), which use the estuary primarily as a nursery ground, usually spawning and spending much of their adult life at sea but often returning seasonally to the estuary; *vi*) the freshwater adventitious species (FW), which occasionally enter brackish waters from fresh waters but have no apparent estuarine requirements.

The data were analysed using a multivariate approach; the sampling stations were clustered according to Bray-Curtis distance (Legendre & Legendre, 1984), by the ecological characteristics of their species, the diversity indexes and by the guilds abundance. The clustering was made using the unweighted, pair-group method using arithmetic averages (UPGMA) (Sneath & Sokal, 1973; Legendre & Legendre, 1984).

The influence of the abiotic parameters on the results of the previous clustering was studied by simple canonical analysis, using the Mahalanobis (D^2) multivariate distance between the abiotic parameters recorded in two clustered groups. The percentage contribution of each abiotic parameter was also estimated

for the multivariate distance of the groups. These calculations were made using NTSYS-pc (Anon, 1989) and SDA.BAS (Ludwig & Reynolds, 1988).

Results

Abiotic Parameters

The Ria de Aveiro is influenced by a marine temperate climate. Water temperature varies from 6.5ºC in the winter to 27.6ºC in the summer. The spatial variation of temperature was not statistically significant (Table 1); however, the observed seasonal temperature amplitudes, in each area, showed significant differences (Table 1).

Table 1 - Two way anova without replication of hydrologic abiotic parameters by sampling stations and months. The statistic test (F) and the probability value (P) and are showed: n.s. (P≥ 0.05); * (P<0.05); ** (P<0.01); *** (P<0.001).

Parameters	Stations		Months	
	F	P	F	P
Temperature	0.254	ns	64.500	***
Salinity	13.990	***	4.744	***
Dissolved oxygen	1.343	*	4.068	***
Transparency	19.860	***	1.167	*

At the channels edges (ARE, CAR, VAG) and at the intermediate stations (LAR, RIO, TOR), where the water turnover is lower, the water temperature followed the air temperature: 20.5 – 27.6ºC in summer and 6.5 – 14.0ºC in winter (Fig. 3).

The salinity significantly varied spatially with typically freshwater (ARE and RIO), brackish water (VAG, LAR and CAR), and marine water, close to the mouth of the lagoon (BAR, SJA, GAF and TOR) (Table 1). Seasonally, salinity variations generally followed those of the temperature (Fig. 3).

The mean spatial variation of dissolved oxygen; although not significant (Table 1), showed levels near the anoxia (1.25 $mg.l^{-1}$, in BAR), intermediate values (7.76 $mg.l^{-1}$, in RIO) and oversaturated values (11.39 $mg.l^{-1}$, in GAF). The seasonal variations of dissolved oxygen were significant and approximately inverse of the temperature and salinity (Fig. 3).

The transparency varied significantly among the stations, between 11.9% (LAR) and 100% (TOR and CAR) (Fig. 3), but the seasonal variation was not significant (Table 1).

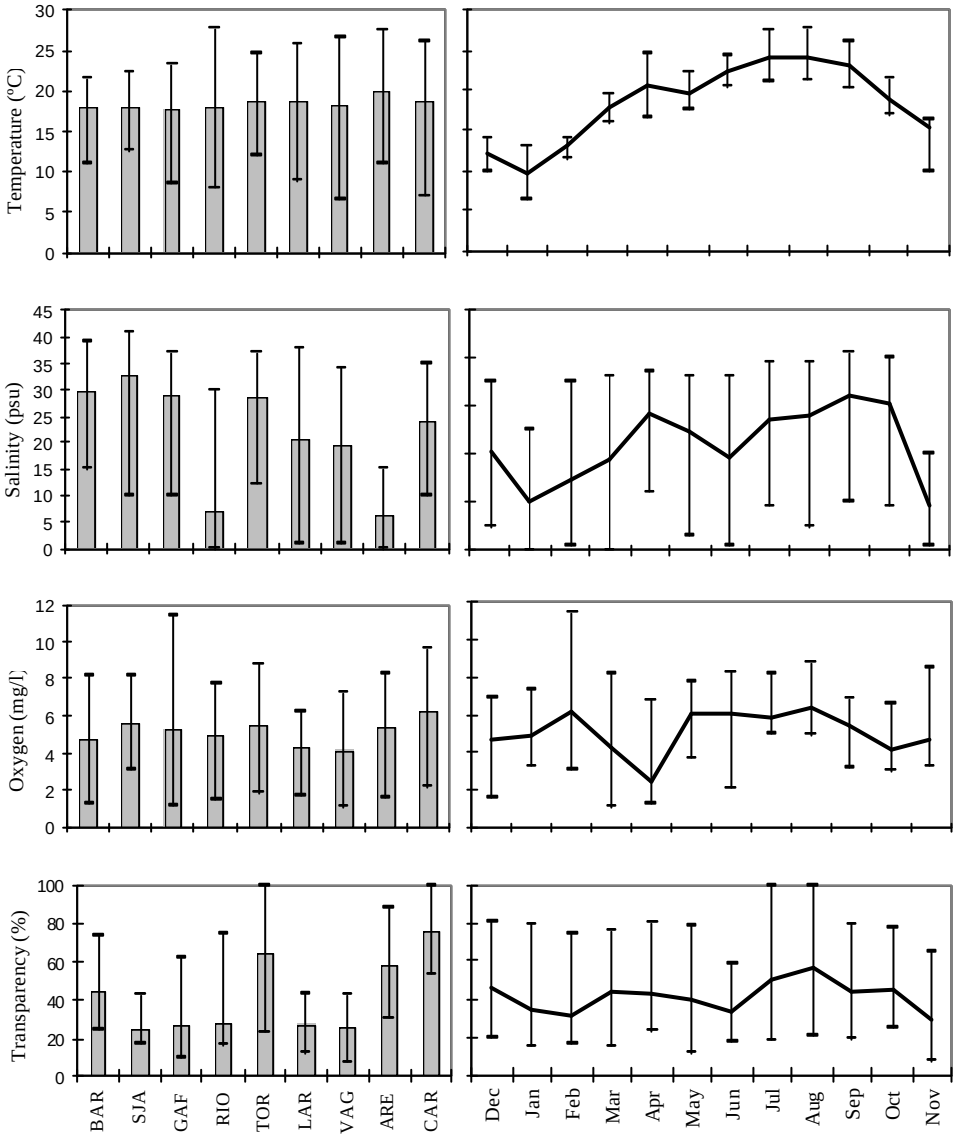

Fig. 3 - Minimum, mean and maximum values of abiotic parameters by sampling stations and months.

Community Structure

A total of 43 teleost species was identified from 14,598 specimens. The data set of the fishfauna density over stations and months is given in table 2. The six most abundant species (marked with an arrow), although not occurring across the

whole lagoon area or during the whole sampling period, represented more than 74% of the total fish abundance.

Table 2 - Species distribution of the fish fauna of the Ria de Aveiro, by sampling stations and months, showing total densities. The species are grouped by ecological categories using the method of Elliott & Dewailly, 1995. The arrow points to the six most abundant species over the whole sampling period.

Ecological categories	Total	Stations									Months											
Species		BAR	SJA	GAF	RIO	TOR	LAR	VAG	ARE	CAR	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
EST. RESIDENT (ER)																						
Aphia minuta	2	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0
Atherina boyeri ←	837	21	95	103	17	100	25	146	66	264	73	89	64	90	73	36	46	63	18	61	100	124
Gobius niger	197	10	0	18	0	166	2	0	0	1	17	11	2	0	23	17	14	20	10	16	61	6
Mugil cephalus	228	3	0	1	4	15	4	7	90	104	67	6	65	54	20	4	6	0	1	4	0	1
Platichthys flesus	16	0	0	1	1	2	0	0	12	0	1	0	0	0	0	8	0	0	1	2	0	4
Pomatoschistus microps	413	36	3	20	6	27	4	172	87	58	1	3	21	19	7	7	22	72	36	36	60	129
Pomatoschistus minutus	28	0	1	2	0	1	1	2	21	0	24	2	0	0	0	0	0	2	0	0	0	0
Symphodus melops	44	0	0	5	0	38	0	0	0	1	11	10	3	3	8	9	0	0	0	0	0	0
Syngnathus abaster	16	0	0	0	0	0	0	0	9	7	0	0	0	0	0	2	0	5	0	1	0	8
Syngnathus acus	662	2	2	0	2	19	5	20	333	279	31	11	40	60	40	87	97	171	43	18	23	41
Syngnathus typhle	38	0	2	1	0	0	1	2	5	27	1	0	0	0	0	0	11	15	1	3	3	4
M. ADVENTITIOUS (MA)																						
Blennius gattorugine	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Callionymus lyra	6	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	3	
Caranx crysos	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	
Echiichthys vipera	22	1	18	0	0	3	0	0	0	0	3	2	2	3	1	3	2	3	3	0	0	0
Mullus surmuletus	59	47	0	9	0	3	0	0	0	0	0	0	0	0	0	0	0	7	18	5	29	0
Oedalechilus labeo	61	0	0	0	0	7	8	0	18	28	61	0	0	0	0	0	0	0	0	0	0	0
Solea lascaris	12	0	0	0	0	9	0	0	3	0	1	0	0	0	0	3	2	4	2	0	0	0
Sparus aurata	36	3	0	2	2	1	1	2	2	23	0	0	0	0	13	13	2	1	2	4	1	0
Symphodus bailloni ←	738	26	1	11	0	697	2	0	1	0	0	0	0	0	0	0	11	46	80	189	397	15
Trachurus trachurus	17	6	0	1	0	0	0	0	1	9	0	0	8	0	0	0	0	0	1	0	7	1
DIADROMOUS (CA)																						
Alosa alosa	17	0	1	1	9	1	3	1	1	0	3	1	1	0	2	1	0	0	0	2	6	1
Alosa falax	40	13	8	5	1	0	11	1	1	0	3	5	4	1	3	4	10	5	1	2	1	1
Anguilla anguilla	287	2	0	1	1	10	0	4	199	70	4	0	1	8	3	10	26	188	33	1	10	3
Liza ramada	247	3	0	18	12	72	12	37	46	47	95	31	0	18	5	6	16	15	16	2	3	40
Liza saliens	667	7	0	10	30	81	38	105	92	304	243	9	9	136	12	7	59	40	9	45	31	67
MAR. SEASONAL (MS)																						
Belone belone	9	9	0	0	0	0	0	0	0	0	0	0	0	0	8	1	0	0	0	0	0	0
Chelon labrosus	455	6	8	32	49	25	49	65	128	93	11	25	114	103	45	55	30	14	18	5	3	32
Engraulis encrasicholus	9	0	0	0	0	0	0	3	6	0	0	0	0	0	0	0	0	0	1	1	7	0
Liza aurata ←	2906	153	33	186	214	836	202	459	570	253	206	88	50	161	536	311	247	385	196	191	136	399
Sardina pilchardus ←	4644	2365	262	488	13	1270	245	1	0	0	0	1	0	1	2	1728	999	808	37	639	429	0
MAR. JUVENILE (MJ)																						
Atherina presbyter ←	833	150	131	232	19	141	47	64	5	44	41	33	44	110	69	103	86	44	45	91	73	94
Dicentrarchus labrax ←	872	40	7	163	37	72	200	190	16	147	61	19	8	129	238	111	47	82	31	128	10	8
Dicentrarchus punctatus	11	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0
Diplodus annularis	15	1	0	3	0	5	0	0	0	6	0	3	0	6	2	3	1	0	0	0	0	0
Diplodus sargus	59	17	0	13	0	29	0	0	0	0	0	0	0	0	0	0	0	1	27	27	2	2
Diplodus vulgaris	11	2	0	6	0	2	1	0	0	0	0	0	0	0	0	0	5	0	3	0	3	0
Scophthalmus rhombus	2	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
Solea senegalensis	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Solea vulgaris	5	0	0	1	1	1	1	0	0	1	0	1	0	0	0	0	0	1	1	1	1	0
Spondyliosoma cantharus	56	29	10	1	0	11	4	0	1	0	0	0	0	0	0	0	0	4	0	5	42	5
Trigla lucerna	17	3	0	0	0	14	0	0	0	0	0	0	1	0	3	13	0	0	0	0	0	0
FRESHWATER (FW)																						
Carassius carassius	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Total density	14598	2958	587	1336	429	3659	866	1281	1714	1768	958	351	439	902	1113	2542	1742	2007	636	1481	1439	988
Number of species	43	28	16	29	18	30	22	18	25	21	21	20	18	16	21	24	24	25	28	26	25	22

The variation of community indices (species richness, diversity and evenness) is shown according to the distance from the mouth of the lagoon and by month in figure 4. Specific richness showed some fluctuations among the sampling stations.

Species diversity and evenness were lower at the mouth of the lagoon; therefore the communities in the upper reaches of the channels were characterised as the best structured of the lagoon (Fig. 4).

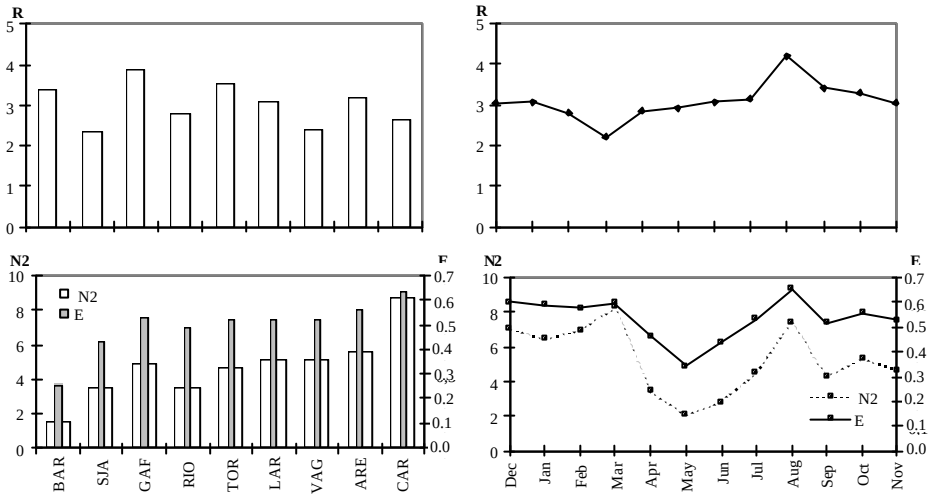

Fig. 4 - Variation of diversity indices by sampling stations and by months. **A**: Margalef index (R); **B**: diversity (N2) and evenness (E).

The cluster analysis (Fig. 5) of sampling stations, in terms of diversity indexes, delimited 4 groups.

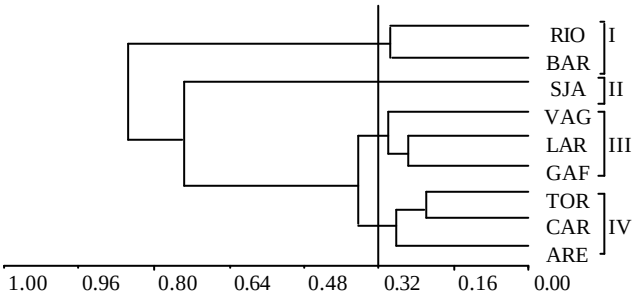

Fig. 5 - Dendrogram of sampling stations, for the diversity indexes. The vertical line defines the groups (I, II, III and IV) used in the discriminant analysis.

RIO and BAR constitute the first group with similar diversity and evenness along the months, which mainly differs from the II and III groups by the transparency (more precisely, the turbidity) and differs from the IV group by the temperature (Table 3). The second group is formed by a single station, SJA, with

particular abiotic characteristics, which mainly differs from the other groups by the transparency (low turbidity and high depth) (Table 3). The group that comprises the areas with higher pollution levels (LAR, VAG and GAF) shows intermediate levels of diversity index and exhibits higher levels of depth comparing to the fourth group. The latter group includes the edges of lagoon (CAR and ARE) and the main channel (TOR), with high levels of species richness and the highest levels of diversity and evenness.

Table 3 - Discriminant analysis between pairs of sampling stations groups, for the diversity indexes, from the medium values of temperature, salinity, dissolved oxygen and transparency. D^2 is the multivariate distance.

	I-II	I-III	I-IV	II-III	II-IV	III-IV
D^2	596475.3	82266.2	101401.7	-5351583.1	745421.3	239416.4
Temperature	-2.4	0.3	**110.8**	0.2	-48.4	82.1
Salinity	116.4	-200.2	3.1	11.9	175.3	-37.1
Dissolved oxygen	-101.1	-42.1	-32.8	-2.3	-34.4	-62.9
Transparency	-33.4	19.6	50.2	**47.7**	**340.2**	**148.1**

Seasonally, species richness showed a general increase from spring to summer, with a single decrease in March and with a peak in August (Fig. 4). The diversity and evenness showed peaks in March and in August. In March the diversity index was the highest (8.3), as a consequence of the occurrence of the eight most dominant species (*Liza aurata*, *Dicentrarchus labrax*, *Atherina presbyter*, *Chelon labrosus*, *Atherina boyeri*, *Syngnathus acus* and *Mugil cephalus*), which represented 93% of the total density. The evenness recorded during that month (0.59) denoted a medially structured community. However, the evenness in August reached the maximum value (0.65). During that month the seven most abundant species showed a reduced density (between 33 and 196 specimens): *L. aurata*, *Symphodus bailloni*, *A. presbyter*, *S. acus*, *S. pilchardus*, *Pomatoschistus microps* and *Anguilla anguilla*. The diversity and evenness indices presented the lowest values in May (2.1 and 0.34, respectively). The two most abundant species, which represented 80% of the total density during that month, were *S. pilchardus* and *L. aurata*. The dominance of these two species (80% of total density) produced a very reduced evenness (0.34).

Spatial and Temporal Variation of Fish Fauna Composition

In order to understand the dynamics of the fish community, species were grouped into the six ecological guilds described above. The frequencies of the number of species, density and biomass of each guild are shown in figure 6 indicating the use and importance of the estuary for fish.

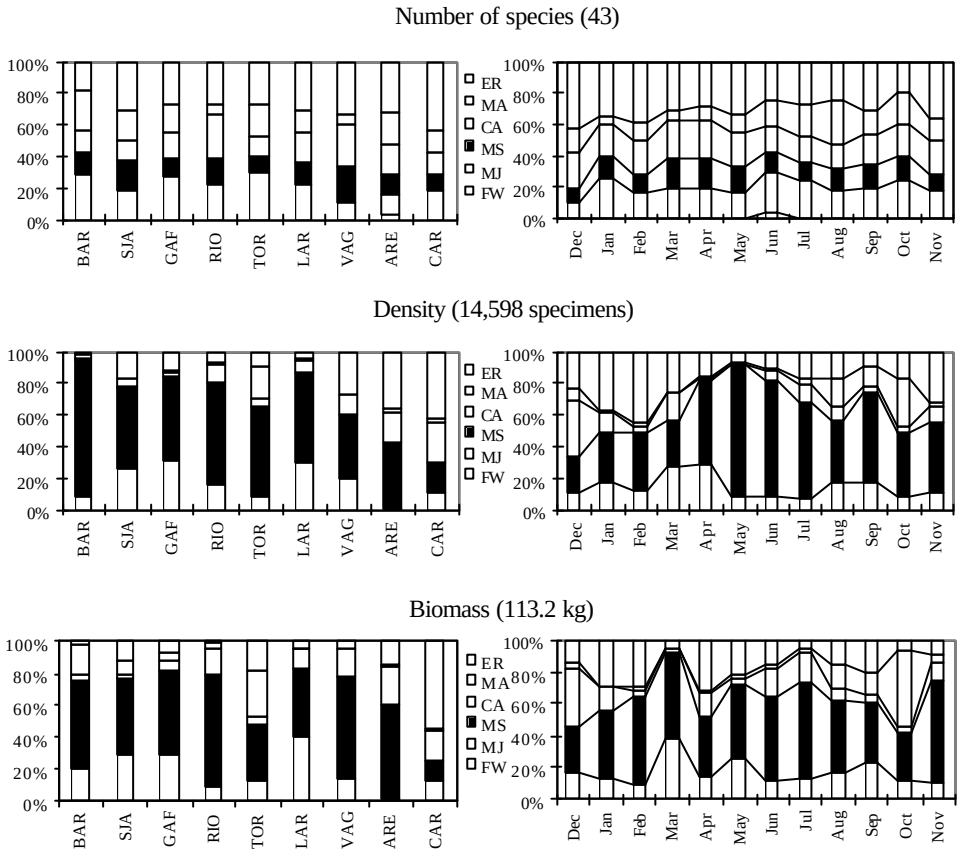

Fig. 6 - Frequencies (%) of the number of species, density and biomass of estuarine resident species (ER), marine adventitious visitors (MA), diadromous (catadromous and anadromous migrant species) (CA), marine seasonal migrant species (MS), marine juvenile migrant species (MJ) and freshwater adventitious

The cluster analysis (Fig. 7) of sampling stations, in terms of ecological guilds, defined 4 groups. BAR constitutes an isolated group with the highest abundance of marine seasonal category (Fig. 6), despite the occurrence of a low number of species (5), represented by higher density (54%) than biomass (46%). This ecological category showed a high proportion at all the sampling stations, especially at BAR with more than 80% of total density (Fig. 6).

From April to July the highest density levels of this category correspond to the recruitment of *S. pilchardus*.

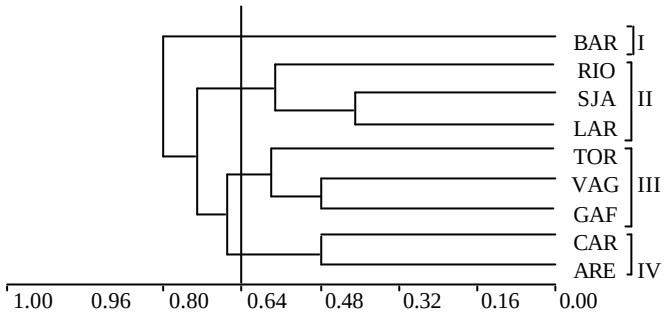

Fig. 7 - Dendrogram of sampling stations, for the ecological guilds abundance. The vertical line defines the groups (I, II, III and IV) used in the discriminant analysis.

The second group comprises the intermediate areas (LAR, RIO and SJA), in which the marine juvenile migrant species presented higher densities than the resident ones (Fig. 6). All the specimens included in this category belong to the families Moronidae, Sparidae and Soleidae, contributing to higher biomass than density (Fig. 6). The main food items of this ecological category are insects, mysids, molluscs, isopods and amphipods. Two species are noticeable for their large distribution in all the lagoon area and for their high density: *A. presbyter* and *D. labrax.* These species contributed to the general predominance of this category in this group during March and April. The station of this group differs from the first and third group by the transparency and from the fourth group especially by the oxygen levels (Table 4). On the TOR, VAG and GAF stations, in spite of high densities of marine seasonal species, the resident species are more abundant than the marine juveniles.

Table 4 - Discriminant analysis between pairs of sampling stations groups, for the ecological guilds abundance, from the medium values of temperature, salinity, dissolved oxygen and transparency. D^2 is the multivariate distance.

	I-II	I-III	I-IV	II-III	II-IV	III-IV
D^2	-1659936.1	-230939.8	262630.5	-218197.8	-767564.3	61225.1
Temperature	0.7	-4.2	-71.8	2.8	-7.3	-78.1
Salinity	30.6	**50.1**	42.3	33.3	7.1	16.8
Dissolved oxygen	3.4	29.6	-15.4	-6.5	**65.8**	-19.8
Transparency	**106.9**	22.1	**143.2**	**111.2**	10.3	**182.6**

The estuarine resident category is mainly characterised by small species, such as gobiidae and syngnathidae, inducing a biomass lower than the density.

The diet of this category is based on isopods, insects and decapods. Compared with BAR the low salinity constitutes the abiotic parameter that contributes to the difference of species occurrence. Compared with the fourth group the low depth constitutes the most important parameter. The north and south edges of the lagoon (CAR and ARE, respectively) showed the highest abundance of resident species, especially during winter. The diadromous species contributed to more than 10% of total density, occurring particularly in this group during December, January and March, corresponding to the period of lagoon recruitment of the species *A. anguilla*, *Alosa* spp. and *Liza* spp. Diadromous species feed mainly on copepods, insects and mysids. This group differs from the others especially by its low transparency (Table 4). The freshwater group shows low representativity in density or biomass because only one *Carassius carassius* was caught.

Discussion

In the estuarine coastal lagoon of Ria de Aveiro, the seasonal climatic variations produce regularly a high number of species, but also contribute to the occurrence of well-adapted species exhibiting high productive potential. The most abundant species occur in Torreira, Barra and Carregal, shallow areas with high levels of transparency and primary production (Rebelo, 1992), suggesting that the preference of these species are related to a high availability of food. Seasonally the most abundant species were found in mid-summer, when the oxygen levels, as well as the primary production, are higher than during the other periods. The biomass showed some flutuations along the year but was higher on the edges of the lagoon than in the other areas. The fishfauna of the Ria de Aveiro is represented by a number of species (43) very similar to other European estuarine ecosystems (Tables 5 and 6).

The species well adapted to the environmental fluctuant conditions of this system stay in the lagoon during all their lifecycles (ER) or depend on the lagoon during their juvenile stage (MJ). These ecological groups have colonised the lagoon since 1912 (Osório, 1912; Nobre *et al*., 1915; Arruda *et al*., 1988; Rebelo, 1992).

Table 5 - List of the European estuaries investigated until now and references (adapted from Elliott & Dewailly, 1995).

Estuary	Country	Latitude	Source of publication
Tagus	Portugal	38º 40' N	Costa and Elliott, 1991
El Abra	Spain	43º 50' N	Elliott and Dewailly, 1995
Loire	France	47º 10' N	Marchand, 1993
Voordelta	The Netherlands	52º 00' N	Hamerlynck, 1993
Humber	England	53º 40' N	Marshall and Elliott, 1998
Elbe	Germany	53º 50' N	Thiel *et al*., 1995
Isefjord	Denmark	55º 50' N	Rasmussen, 1973
Oslofjord	Norway	59º 10' N	Nash, 1988
Ria de Aveiro	Portugal	40º 40' N	Present study

Table 6 - Summary of the sampling effort for each estuary given in Table V, number of species and families of fish fauna (adapted from Elliott & Dewailly, 1995).

Estuary	Period	Frequency	Stations	Species	Families	Gear
Tagus	1976-91	monthly	6	45	23	Beam trawl
El Abra	1989-93	annually	7	23	16	Beam trawl
Loire	1981-82	monthly	unknown	36	24	Beam trawl
Voordelta	1989	monthly	22	40	24	Beam trawl
Humber	1992-93	quarterly	14	26	18	Beam trawl
Elbe	1989-92	unknown	11	62	28	Framed gape stow net, Demersal otter trawl
Isefjord	1940-70	monthly	110	70	38	Commercial, angling, beam trawl
Oslofjord	1981-82	unknown	2	40	20	Bag beach seine
Ria de Aveiro	1996-97	monthly	9	43	21	Purse seine-type net ("chincha")

The marine seasonal species (MS) occurred in higher abundance at the entrance of the lagoon and during summer, corresponding to a period of intensive migratory activity.

Sardina pilchardus and *Liza aurata* are noticeable in this group for their high abundance. The diversity of marine seasonal species (MS) is lower than of resident species (ER), like in other estuaries of the Atlantic coast (Table 7).

The adventitious species (MA) accidentally visit the lagoon because of currents or for trophic motivations (Rebelo, 1992). In other European estuaries, such as El Abra, in Spain (Elliott & Dewailly, 1995) and Isefjord, in Denmark (Rasmussen, 1973) (Table 7), the number of species in this group is higher than in our study, reaching more than 40% of all species. In the present study, although the number of species is very similar to the other categories the abundance was very low.

Table 7 - Percentage of number species in the ecological guild for each estuary given in Table V. ER - estuarine resident species; MA - marine adventitious visitors, CA - diadromous (catadromous and anadromous migrant species), MS -marine seasonal migrant species, MJ - marine juvenile migrant species, FW - freshwater adventitious species (adapted from Elliott & Dewailly, 1995).

Estuary	ER	MA	CA	MS	MJ	FW
Tagus	25	16	13	13	29	4
El Abra	18	48	4	9	22	0
Loire	14	20	14	9	31	11
Voordelta	30	25	5	10	30	0
Humber	31	15	15	8	31	0
Elbe	19	13	13	8	16	31
Isefjord	24	41	9	10	14	1
Oslofjord	33	28	8	8	23	3
Ria de Aveiro	25	23	12	12	26	2

The dominant species in this group, *Symphodus bailloni* was very abundant in a region, Torreira, and during a period, between June and November, when the salinity values were close to the marine water, approximately 30 psu. The species that use estuaries as a nursery (MJ) occur at low salinity values. It is noticeable that *Dicentrarchus labrax* and *Atherina presbyter* dominate the other nine species of this category. These fish (MJ) are also well distributed in all the other European coastal lagoons (Table 7).

Catadromous species (CA), which include *Anguilla* spp., *Alosa* spp. and some *Liza* spp., are well represented in terms of number of species (12) compared to other European lagoons, from 4 species in El Abra, in Spain (Elliott & Dewailly, 1995) to 15 species in the Humber Estuary, in England (Marshall & Elliott, 1998). The freshwater species category (FW) comprised only one species, *Carassius carassius*, which distribution is restricted to Areão, with an average salinity of 6. This category is not known to occur in some Atlantic estuaries (Rasmussen, 1973; Nash, 1988; Costa & Elliott, 1991; Hamerlynck, 1993; Elliott & Dewailly, 1995; Thiel *et al*., 1995; Marshall & Elliott, 1998), but is abundant in others (Elbe) where the salinity may be low. Transparency was the most influencial factor, followed by salinity, in the colonization of the stations found in the intermediate and near entrance sites. The edges of the lagoon, due specially to their transparency but

also their dissolved oxygen levels, constitute a preferential area of colonization by resident and seasonal species.

In global terms, the fish community in this system had only a few very abundant species (5) compared to the total number of captured species (43). The total number and the number of very abundant species in this work were lower than in the previous work on this lagoon by Rebelo (1992) who found 7 very abundant species for a total of 55 species (Table 8). When both studies are cumulated, 62 species are known from Ria de Aveiro. The density of *Gobius niger* and *Liza ramada* highly decreased in the recent study. There are 19 species that exclusively occurred in Rebelo, 1992 while only 7 species have exclusive occurrence in the present work (Table 8). In about 10 years, the level of evenness of the population of lagoon has slightly decreased. This fact could be related with the recent human actions that have been affecting this estuarine system, namely the extraction of sediments from the lagoon and an increase in fishing effort (artisanal and recreational).

Between 1988 and 1997 more than 5 10^6 m^3 of sand were extracted from the main navigator channel and more than 3 10^6 m^3 of sand were extracted from the inner to the outer side of the lagoon, with deposition along beaches and in the sea. Ria de Aveiro is well represented in number of species (62) compared with other estuarine lagoon systems: El Abra, in Spain (23 species) (Elliott & Dewailly, 1995) and Isefjorf, in Denmark (70 species) (Thiel *et al*., 1995) (Table 5 and 6).

Latitude does not seem to play an important role, amongst European estuaries, according to table 6. However this could be related to differences in sampling methods and effort. Differences in transparency between the medium sites and the edges of the lagoon could explain these changes. The temperature may also influence the different levels of diversity between the entrance of the lagoon and its edges. On the edges, the temperature is higher and the vegetation can grow intensely, allowing mainly the colonization by resident species (*Pomastoschistus microps*, *Mugil cephalus* and *Syngnathus acus*), protecting them against predation and supplying a high food supply.

Table 8 - Ranking in abundance of species in 1987 (Rebelo, 1992), at ten sampling stations, and in the present study, 1996/97, at nine sampling stations. The same sampling method was used in both studies. In bold are the species specific to each study. The circled mark is referred to the very abundant species in both studies.

Family	Species	1987	1996/97
Clupeidae	*Sardina pilchardus* (Waulbaum, 1792)	826	4644
Mugilidae	*Liza aurata* (Risso, 1810)	1755	2906
Moronidae	*Dicentrarchus labrax* (Linnaeus, 1758)	871	872
Atherinidae	*Atherina boyeri* (Risso, 1810)	5976	837
Atherinidae	*Atherina presbyter* Cuvier, 1829	3185	833
Labridae	*Symphodus bailloni* (Valenciennes, 1839)	199	738
Mugilidae	*Liza saliens* (Risso, 1810)	629	667
Syngnathidae	*Syngnathus acus* Linnaeus, 1758	704	662
Mugilidae	*Chelon labrosus* (Risso, 1826)	38	455
Gobiidae	*Pomatoschistus microps* (Krøyer, 1838)	0	**413**
Anguillidae	*Anguilla anguilla* (Linnaeus, 1758)	753	287
Mugilidae	*Liza ramada* (Risso, 1826)	1247	247
Mugilidae	*Mugil cephalus* Linnaeus, 1758	16	228
Gobiidae	*Gobius niger* Linnaeus, 1758	802	197
Mugilidae	*Oedalechilus labeo* (Cuvier, 1829)	4	61
Sparidae	*Diplodus sargus* (Linnaeus, 1758)	22	59
Mulliidae	*Mullus surmuletus* Linnaeus, 1758	0	**59**
Sparidae	*Spondyliosoma cantharus* (Linnaeus, 1758)	14	56
Labridae	*Symphodus melops* (Linnaeus, 1758)	49	44
Clupeidae	Alosa fallax (Lacepède, 1803)	18	40
Syngnathidae	*Syngnathus typhle* Linnaeus, 1758	16	38
Sparidae	*Sparus aurata* (Linnaeus, 1758)	167	36
Gobiidae	*Pomatoschistus minutus* (Pallas, 1770)	295	28
Trachinidae	*Echiichthys vipera* (Cuvier, 1829)	85	22
Triglidae	*Chelidonichthys lucerna* (Linnaeus, 1758)	98	17
Carangidae	*Trachurus trachurus* (Linnaeus, 1758)	0	**17**
Clupeidae	*Alosa alosa* (Linnaeus, 1758)	0	**17**
Syngnathidae	*Syngnathus abaster* Risso, 1826	188	16
Pleuronectidae	*Platichthys flesus* (Linnaeus, 1875)	156	16
Sparidae	*Diplodus annularis* (Linnaeus, 1758)	2	15
Soleidae	*Solea lascaris* (Risso, 1810)	9	12
Sparidae	*Diplodus vulgaris* (E. Geoffrey Saint-Hilaire, 1817)	11	11
Moronidae	*Dicentrarchus punctatus* (Bloch, 1792)	0	**11**
Engraulidae	*Engraulis encrasicholus* (Linnaeus, 1758)	7	9
Belonidae	*Belone belone* (Linnaeus, 1761)	2	9
Callionymidae	*Callionymus lyra* Linnaeus, 1758	95	6
Soleidae	*Solea solea* (Linnaeus, 1758)	4	5
Gobiidae	*Aphia minuta* (Risso, 1810)	83	2
Scophthalmidae	*Scophthalmus rhombus* (Linnaeus, 1758)	36	2
Soleidae	*Solea senegalensis* Kaup, 1858	26	1
Cyprinidae	*Carassius carassius* (Linnaeus, 1758)	8	1
Blennidae	*Parablennius gattorugine* (Linnaeus, 1758)	0	**1**
Pomatomidae	*Caranx crysos* (Mitchill, 1815)	0	**1**
Gobiidae	*Deltentosteus quadrimaculatus* (Valenciennes, 1837)	**198**	0
Gasterosteidae	*Gasterosteus aculeatus* Linnaeus, 1758	**151**	0
Gobiidae	*Gobius strictus* Fage, 1907	**128**	0
Poecilidae	*Gambusia affinis* (Baird & Girard, 1853)	**59**	0
Labridae	*Labrus viridis* Linnaeus, 1758	**20**	0
Gobiidae	*Gobius ater* Belloti, 1888	**19**	0
Blenniidae	*Parablennius gattorugine* (Linnaeus, 1758)	**18**	0
Ammodytidae	*Ammodytes tobianus* Linnaeus, 1758	**13**	0
Cobitidae	*Cobitis taenia* Linnaeus, 1758	**7**	0
Gadidae	*Gaidropsarus mediterraneus* (Linnaeus, 1758)	**6**	0
Tetraodontidae	*Lagocephalus lagocephalus* (Linnaeus, 1758)	**3**	0
Ammodytidae	*Hyperoplus lanceolatus* (Le Sauvage, 1824)	**2**	0
Gadidae	*Ciliata mustela* (Linnaeus, 1758)	**2**	0
Gobiidae	*Gobius paganellus* Linnaeus, 1758	**2**	0
Blenniidae	*Parablennius sanguinolentus* (Pallas, 1814)	**1**	0
Cottidae	*Taurulus bubalis* (Euphrasen, 1786)	**1**	0
Petromyzontidae	*Petromyzon marinus* Linnaeus, 1758	**1**	0
Sparidae	*Pagellus bogaraveo* (Brunnich, 1768)	**1**	0
Syngnathidae	*Hippocampus hippocampus* (Linnaeus, 1758)	**1**	0
	62 species		

The species richness increased along the year, except in March, when it showed a decrease, corresponding to the seaward migration of some seasonal migrant species, namely *Liza aurata*. The diversity and evenness were higher in spring and in the middle of summer. According to Bennett (1989) and Monteiro (1989), the seasonal variation of number, distribution and density of species in the lagoon system is more related with the migratory activity than with the variation of abiotic parameters.

However, in this study, the temperature and the salinity allow to split the year into three seasonal discontinuities: November to April, May, and June to October. The first period corresponds to low temperature and salinity and high migration levels of seasonal migrant species. May is characterised by the massive recruitment of schooling species, especially *Sardina pilchardus*, which disturbs the evenness of the system, as well as the diversity index. The last period, from June to October, corresponds to the entrance in the lagoon of the catadromous species *Anguilla anguilla* and the adventitious species *Symphodus bailloni*, which comprises the best structured period with higher specific diversities.

It may be concluded that as the other European estuarine lagoon ecosystems (Alcolado, 1996), the fish community in the Ria de Aveiro can be organized in a well-defined seasonal and spatial patterns. This ecotone is greatly influenced by the abiotic conditions that affect the ichthyological system since it supports abundant sedentary species, provides a suitable nursery area to marine migratory species and is sought by many occasional species, particularly in their juvenile stage, as the other estuarine ecosystems in general (Leeuwen *et al*., 1994).

Acknowledgements

We would like to thank people who helped in the field and lab work and the University of Aveiro that supported this study. We are very grateful to Professor Mike Elliott for his precious advice and review of the manuscript. Thanks to the reviewers that improved the paper by their remarks.

References

Alcolado, P.M. 1996. Controversia sobre la relación entre la diversidad de especies y la estabilidad de las comunidades. *Avicennia,* 4/5: 13-26.

Anon. 1989. NTSYS-pc. Version 1.5. Applied Biostatistics Inc.

Arruda, L.M.; Andrade, J.P. & Cunha, M.M. 1988. Abundance, diversity and community structure of the fish population in the Ria de Aveiro (Portugal). *Oceanol. Acta,* 11 (3): 235-240.

Barrosa, J.O. 1980. A Ria de Aveiro e a sua influência na economia da região. *Recur. hídr.,* 1 (3): 83-96.

Bauchot, M.L. & Pras, A. 1987. *Guía de los peces de mar de España y de Europa*. Ediciones Omega, Barcelona.

Bennett, B.A. 1989. The fish community of a moderately exposed beach on the Southwestern Cape Coast of South Africa and an assessment of this habitat as a nursery for juvenile fish. *Estuar. Coast. Shelf Sci*., 28: 293-305.

Borrego, C., Cruz, M.M. & Gonçalves, P. 1994. *Estudo de avaliação da vulnerabilidade da capacidade de recepção das águas costeiras em Portugal. Relatório R 3.2. Meios receptores e suas características: (Be 1) - Ria de Aveiro, Pateira de Fermentelos e Barrinha de Mira*. Projecto nº 13/94. IDAD, Aveiro.

Costa, M.J. & Elliott, M. 1991. Fish usage and feeding in two industrialised estuaries - the Tagus, Portugal, and the Forth, Scotland. In: Olsen and Olsen (Eds.), *Estuaries and Coasts: spatial and temporal intercomparisons*. Fredensborg, Denmark. 289-297. p.

Elliott, M. & Dewailly, F. 1995. The structure and components of European estuarine fish assemblages. *Neth. J. Aquac. Ecol*., 29 (3-4): 397-417.

Elliott M.; O'reilly, M.G. & Taylor, C.J.L. 1990. The Forth estuary: a nursery and overwintering area for North Sea fishes. *Hydrobiologia*, 195: 89-103.

Hamerlynck, O. 1993. The ecology of *Pomatoschistus minutus* and *Pomatoschistus lozanoi* de Buen (Pisces, Gobiidae) in the shallow coastal waters and estuaries of the Southern Bight of the North sea. Ph.D. Thesis, University of Gent, Belgium.

Hill, M.O. 1973. Diversity and evenness: A unifying notation and its consequences. *Ecologie,* 54: 427-432.

Legendre, L. & Legendre, P. 1984 a. *Écologie numérique. Le traitement multiple des données écologiques,* 2e ed. Masson et Les Presses de l'Université du Québec, Paris.

Legendre, L. & Legendre, P. 1984 b. Écologie numérique. *La structure des donnés écologiques,* 2e ed. Masson et Les Presses de l'Université du Québec, Paris.

Leeuwen, P.I. van; Rijnsdorp, A.D. & Vingerhoed, B. 1994. Variations in abundance and distribution of demersal fish species in the coastal zone of the Southeastern North Sea between 1980 and 1993. *Demersal Fish Comm.,* 10: 1-19.

Lima, C. 1986. Impacto da poluição por mercúrio nos organismos aquáticos da Ria de Aveiro. *Relat. Inst. Nac. Invest. Pescas*, 66: 1-28.

Lucas, M.F.; Caldeira, M.T.; Hall, A.; Duarte, A.C. & Lima, C. 1986. Distribution of mercury in the sediments and fishes of the lagoon of Aveiro, Portugal. *Water Sci. Technol.*, 18: 141-148.

Ludwig, J.A. & Reynolds, J.F. 1988. *Statistical Ecology. A primer on Methods and Computing*. Wiley-Interscience Publications, New York.

Marshall, S. & Elliott, M. 1998. Environmental influences on the fish assemblage of the Humber Estuary, UK. *Estuar. Coast. Shelf Sci.*, 46: 175-184

Monteiro, C.L.C. 1989. La faune ichthyologique de la lagune Ria Formosa (sud Portugal). PhD. Thesis, Instituto Nacional de Investigação das Pescas, Algés, Portugal.

Nash, R.D.M. 1988. The effects of disturbance and severe seasonal fluctuations in environmental conditions on north temperate shallow-water fish assemblages. *Estuar. Coast. Shelf Sci.,* 26: 123-125.

Nobre, A.; Afreixo, J. & Macedo, J. 1915. *A Ria de Aveiro, Relatório oficial do regulamento da Ria de 28 de Dezembro de 1912*. Imprensa Nacional, Lisboa.

Osório, B. 1912. Pescas e peixes. Uma nota relativa à pesca e aos peixes da Ria de Aveiro. *Bol. Soc. Geogr. Lisboa*, 30 (4-5): 216-224.

Pomfret, J.R.; Elliott, M.; O'reilly, M.G. & Phillips, S. 1991. Spatial and temporal patterns in the fish communities in two UK North Sea estuaries. *Estuar. Coasts: Spat. Temp. Intercomp.,* 87: 277-284

Potter, I.C.; Beckley, L.E.; Whitfield, A.K. & Lenanton, R.C.J. 1990. Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and Southern Africa. *Environ. Biol. Fish.,* 28: 143-178.

Rasmussen, E. 1973. Systematics and ecology of the Isefjord marine fauna (Denmark). *Ophelia,* 11: 1-507.

Rebelo, J.E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries,* 15(3): 403-415.

Sneath, P.H.A. & Sokal, R.R. 1973. *Numerical Taxonomy*. W.H. Freeman and Company, San Francisco.

Sokal, R.R. & Rohlf, J.F. 1995. *Biometry.* 3rd ed., W.H.Freeman and company, New York.

Whitehead, P.J.P.; Bauchot, M.-L., Hureau, J.-C.; Nielsen, J. & Tortonese, E. 1986. *Fish. North-eastern Atl. Med.* 3 vols. UNESCO, U.K.

Thiel, R.; Sepulveda, R.; Kageman, R. & Nellen, W. 1995. Environmental factors as forces structuring the fish community of the Elbe estuary. *J. Fish Biol.*, 46:47-69.

Zar, J.H. 1984. *Biostatistical Analysis.* 2nd ed. Prentice-Hall, Inc., New Jerse.

The Structure and Functioning of Fish Communities in the Ria de Aveiro, Portugal – Temporal and Spatial Variation and the Influence of Abiotic Factors

Pombo, L.; Elliott, M. & Rebelo, J.E. 2004.

Cahiers de Biologie Marine 45: 197-211

The Structure and Functioning of Fish Communities in the Ria de Aveiro, Portugal – Temporal and Spatial Variation and the Influence of Abiotic Factors

Abstract

The ichthyofauna and environmental variables were sampled monthly over a 2-year period, from November 1998 to October 2000, at 9 sites in the Ria de Aveiro, northern Portugal. Temperature, salinity, dissolved oxygen, pH and turbidity showed significant temporal variation, while salinity, pH, turbidity and depth showed significant spatial variation. A total of 41,681 individuals from 61 species were collected, with a total biomass of 222 Kg wet weight. Species richness was statistically higher in 1999 than in 2000, with peaks in spring-summer in both years, which could be attributed to an influx of marine seasonal migrant species and marine juvenile species. Diversity and evenness were significantly higher in 1999 than 2000 with peaks in spring and autumn and low values in May, June and August, for both years corresponding to the large recruitment of *Sardina pilchardus*. Spatially, both indices were higher at the intermediate regions than at the lagoon mouth. Temperature was found to be the best predictor of total abundance, while salinity was the abiotic factor that showed the strongest relationship with fish biomass. Temperature, salinity and pH were positively correlated with species richness and depth was negatively correlated with species richness. It is concluded that the abiotic factors were related to the distribution and diversity of the ichthyofauna such that seasonal changes in abiotic factors appeared to be of greater importance in explaining variation in the fish communities than location within the lagoon.

Keywords: fish diversity, estuarine lagoon, abiotic variables, Ria de Aveiro.

Introduction

Assemblages of estuarine organisms change continually in time and space, largely because estuaries serve as nurseries for many marine and estuarine dependent species (Rogers *et al*., 1984 *in* Rakocinski *et al*., 1996; Elliott &

Hemingway, 2002). The habitats and, therefore, potentially the fish assemblages, can be affected by anthropogenic influences that vary with time and space. These impacts can have a direct influence on the food resources, distribution, abundance, growth, survival and behaviour of fish in aquatic environments (Whitfield, 1996). The linkages between the changes in the ichthyofauna and environmental variation in estuaries suggest that fish species or fish communities are sensitive indicators of the relative health of an aquatic ecosystem (Karr, 1981). The importance of estuaries for fish has resulted in environmental quality objectives (EQO) being adopted to manage estuaries, to protect estuarine habitats and to ensure that water quality is suitable for sustaining healthy fish populations (Elliott *et al*., 1988). These fish-orientated EQO include: (i) the water quality always allows the passage of migratory fish; (ii) the estuary's residential fish community is consistent with the hydro physical conditions; (iii) the benthos and sediments are of sufficient quality to support the fish populations, and (iv) the levels of persistent toxic and tainting substances in the biota should be insignificant and should not affect predatory fish (Elliott *et al*., 1988). According to Whitfield (1996), biological monitoring is preferred to chemical monitoring because the latter can fail to detect many of the anthropogenic-induced perturbations of aquatic systems and biological monitoring will integrate all changes occurring in the environment.

In order to determine whether the perceived degradation of a system is actual and to what degree it has occurred, it is necessary to distinguish between natural and anthropogenic changes to the biological assemblages in that system over space and time (Matthews, 1998). However, multispecies assemblages vary greatly and are rarely quantified over both space and time (James, 2001). Despite this, recent developments in estuarine and coastal management within Europe, such as the European Union Water Framework (WFD) and Habitats Directives, require further study on the status of priority habitats such as estuaries and lagoons. It is of note that the WFD requires reference conditions to be derived for the fish communities of transitional waters, which includes estuaries and lagoons, against which anthropogenic change can be judged.

The Ria de Aveiro is an estuarine lagoon ecosystem, with one narrow entrance to the sea; it is an ecotone with fluvial and marine influences, shallow

depth, high turbidity, high nutrients, muddy substratum and seasonal fluctuations of temperature, salinity, dissolved oxygen, pH and turbidity. The system also has considerable fish diversity (Rebelo, 1992; Pombo & Rebelo, 2002; Pombo *et al*., 2002) but also provides an important area for the exploitation of commercial and sport fisheries. The ecological studies of ichthyofauna in this system assume considerable economic relevance due to the exploitation of fish within the lagoon.

The lagoon represents an area of considerable economic importance for the region: i) in the primary sector - agriculture, fisheries, aquaculture, and salt-production; ii) in the secondary sector, as a dominant area for industry in the region of Aveiro; iii) in the tertiary sector - tourism, particularly water-borne sports, sport fisheries, passenger transport and services associated with these practices. These activities affect the quality of the water and the sediments of the lagoon by the introduction of chemical, organic and microbial pollutants (Lucas *et al*., 1986; Borrego *et al*., 1994). Thus, the lagoon receives considerable raw and treated wastewater effluent such that three main pollution types are apparent: organic and chemical pollution from paper-pulp factories (in the rivers of Vouga and Antuã); chemical pollution, particularly mercury, from the industrial area of Estarreja (in Laranjo area); and microbial contaminants from the urban sewage effluent and cattle raising areas (Ílhavo channel, Vouga river and Ovar channel) (Hall, 1980; Lima, 1986; Lucas *et al*., 1986; Borrego *et al*., 1994).

Previous studies of ichthyofauna in this lagoon (Osório, 1912; Nobre *et al*., 1915; Arruda *et al*., 1988; Rebelo, 1992; Pombo & Rebelo, 2000, 2002) provide information on the behaviour and evolution of the lagoon fish assemblage (Pombo *et al*., 2002) and their relation with the adjacent oceanic communities.

The present study was designed to characterise the fish assemblages occurring in a typical estuarine lagoon in the littoral of Portugal and to detect significant temporal and spatial differences in those assemblages. It aimed to identify correlations between species assemblages with different ecological guilds and abiotic conditions and to identify factors responsible for maintaining the structure of fish assemblages. The results of this work provide baseline information for monitoring the status of and change within these systems and for comparisons with similar lagoonal systems.

Material and Methods

Study Area

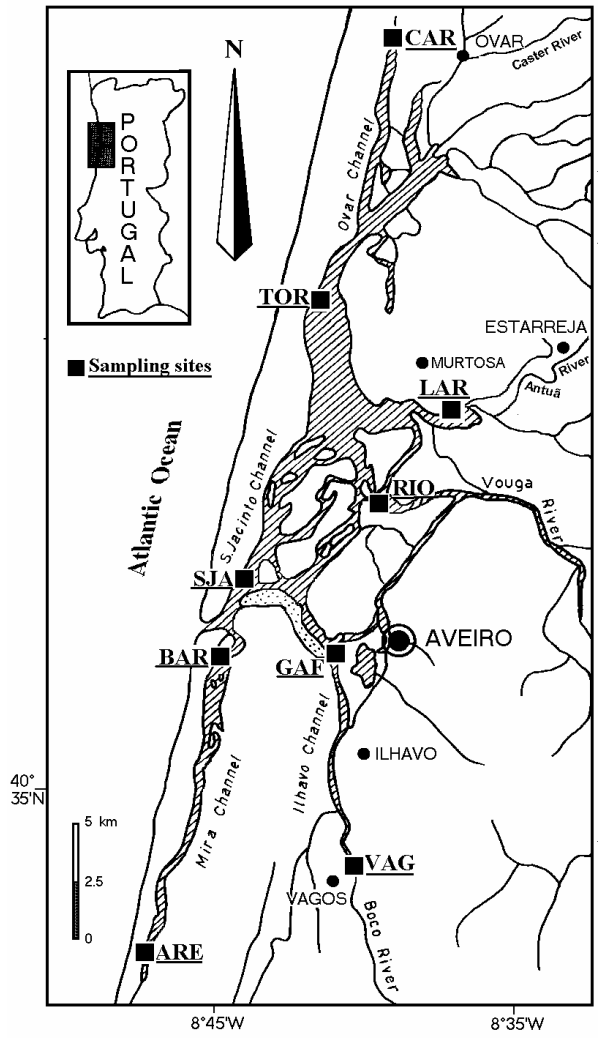

Fig. 1 - Map of the Ria de Aveiro showing sampling sites.

The Ria de Aveiro (Fig.1), on the west coast of Portugal, is an estuarine lagoon, 45 km long with a maximum width of 11 km. Its total area is between 42 km² at low tide, and 47 km² at high tide (Barrosa, 1980). The depth at low tide is only 1 m over much of the lagoon, but can reach 10 m near the mouth and in the navigation channels. Riverine freshwater is mixed with seawater entering from the mouth and the tidal input is approximately between 25 and 90 $x10^6$ m^3 for tidal amplitudes of 1 and 3 m respectively. The water volume is 70 million m^3, with an oceanic tidal contribution between 25 million m^3 (neap-tides) and 90 million m^3 (spring tides). Four rivers (Vouga, Antuã, Caster and Boco) and innumerable streams flow into it at a rate between 3 m^3s^{-1} and 60 m^3s^{-1}, depending on the seasonal precipitation and run-off patterns. Communication with the sea is through a 400 m wide entrance in the coastal sand-bar structure (Barrosa, 1980) and the currents produced by this tidal action are significant only at the mouth, the central part of the main channels and a few other restricted areas. There is a delay of 6 hours in the times of high and low water between the mouth and the extreme margins of the lagoon. The sediment composition, in particular the granulometry, is extremely variable and varies

between 20 to 90% sand, 10 to 80% of silt and 0 to 30% of clay. The inner lagoonal areas have accreting conditions as shown by the northern finer sediments which become progressively coarser to the south (Borrego *et al*., 1994).

Sampling Method

The ichthyofauna was sampled monthly from November 1998 to October 2000 at nine sampling sites (Fig.1). The first twelve months of sampling are designated as 1999 and the second as 2000. At each site and each month, 3 non-overlapping replicate samples were taken at low spring tide, over the five days of the new moon. The total area enclosed by the gear was approximately 193 m^2 in each trawl. A "chincha" or traditional beach-seine net (Nobre *et al*., 1915) was used to sample fish. The "chincha" gear used was almost rectangular in shape and composed by a central bag (a 'cod-end', 295 cm of length and 145 cm of wide), two lateral wings (12 m of length each, the width decreasing along the net, reaching 50 cm at the edge), two ropes (6.1 m each), floating buoys at the top and ceramic weights at the bottom of the net. The stretched mesh sizes in the gear were 19 mm at the wings, 17 mm at the cod mouth, 16 mm at the cod sleeve, and 10 mm at the cod-end. The end of the net was fixed to the margin and the remainder was trawled in a semi-circle thus retaining within the cod-end all the fish from the area. The net efficiency is estimated at 90% (Elliott & Hemingway 2002).

The abiotic parameters temperature, salinity, dissolved oxygen; pH, turbidity and depth were recorded at each site and each month, according to previous studies (Rebelo, 1992; Pombo & Rebelo, 2000, 2002). Temperature (± 0.1 ºC) and dissolved oxygen (± 0.01 $mg.l^{-1}$) were recorded with an oxygen meter (*Consort Z621*), the salinity (± 0.1 psu) with a refractometer (*Atago*), the pH (± 0.01) with a pHmeter (*WTW 330/set – 2*), the turbidity (± 0.1 m) with a Secchi disc and the depth (± 0.1 m) with a handmade probe. The abiotic parameters were spatially and temporally compared between the two years of sampling.

After capture, fishes were preserved by freezing, and were individually identified in the laboratory according to Whitehead *et al*. (1986) and Bauchot & Pras (1987). The total fresh weight was measured with an electronic balance (And FX – 300).

Data Analysis

Species were grouped into ecological guilds using the method of Elliott & Dewailly (1995) according to their biology and behaviour and using background information for the lagoon (Osório, 1912; Nobre *et al*., 1915; Arruda *et al*., 1988; Rebelo, 1992; Pombo & Rebelo, 2000, 2002). The categories were: estuarine resident species, marine juvenile migrant species, marine seasonal migrant species, freshwater adventitious species, marine adventitious visitors and diadromous (catadromous or anadromous) migrant species.

Factors including month, site, year, and interaction terms between them (month*site, month*year, site*year, and month*site*year) were tested for the abiotic parameters and for the diversity indices (species richness, species diversity and evenness indices) using two-way ANOVA and three- way ANOVA (Zar, 1984; Sokal & Rohlf, 1995). Homogeneity of variances was tested using the Fmax test (Zar, 1984; Sokal and Rohlf, 1995). Square root transformations of temperature and salinity and $\log_{10}$ transformations of Shannon-Wiener and evenness were performed to comply with assumptions of the analysis (Zar, 1984; Sokal and Rohlf, 1995). The package Sigma-stat for windows version 2.03 was used for these analyses.

Species richness, species diversity and evenness indices were used to characterise the temporal and spatial abundance of the ichthyofauna (Ludwig & Reynolds, 1988). The species richness (R) was quantified by the Margalef index (Ludwig & Reynolds, 1988): $R = \frac{S-1}{\ln(n)}$, where *S* indicates the total number of species and *n*, the total number of individuals in a sample. Species diversity was quantified using the Shannon-Wiener index (*H'*) (Shannon & Weaver, 1949): $H' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right], i = 1,2,3,\ldots,S$ where *S* indicates the total number of species, n_i the abundance of the *i* species, and *n* the abundance of all species. Evenness (E) was quantified by the index modified by Hill (1973): $E = \frac{\frac{1}{l}-1}{e^{H'}-1} = \frac{N_2-1}{N_1-1}$, where l represents the Simpson index, *H´* the Shannon-Wiener index and N_2 and N_1 represents the diversity number.

Pearson parametric (product-moment) correlation coefficients were used to determine the statistical significance of any relationship between species richness and diversity indices and each abiotic factor to identify which parameter contributes to explaining the structure of fish assemblages in each year (Sokal & Rohlf, 1995). Similarly, Pearson correlations were used to determine the statistical significance of any relationships between fish (abundance and biomass) and abiotic factors to be analysed individually (Sokal & Rohlf, 1995), thus determining the independent variables most likely to explain the distribution of each species together with the nature of the effect.

Seasonal and spatial patterns in habitat structure and fish communities were examined by use of multivariate cluster and ordination techniques. A cluster (classification) analysis was performed using the Bray-Curtis similarity coefficient and UPGMA (unweighted, pair-group, methods using arithmetic averages) linkage method (Boesch, 1977) and a multi-dimensional scaling (MDS) ordination was carried out on log-transformed ($\log_{10}x+0.1$)) species abundance and biomass data (ter Braak, 1988). This strong transformation was chosen so that the few highly abundant (or with high biomass) species would not be over-emphasized in the determination of clusters. The package MVSP (Multi-Variate Statistical Package) (Kovac, 1998) was used for these analyses. To identify temporal and spatial variation in fish structure, pie-charts were produced based on relative abundance of the observed species in each cluster. A further ordination technique, canonical correspondence analysis (CCA) was used as a dual ordination of the species (R-mode) and sites (Q-mode) data together with the environmental parameters (Ter Braak, 1988). To avoid problems associated with the "arch effect" of correspondence analysis, only the ten most abundant species (Fig. 2) were included in the analysis (Jongman *et al*., 1995). CCA gave an assessment of the relative importance of the parameters to the distribution of each of these ten species (Ter Braak, 1988).

Results

Abiotic Parameters

The average, minimum and maximum values of the environmental data in each month and site for each year are shown in figures 2 and 3. Each sampling site is presented in the graphs according to the minimum distance from the lagoon entrance. Each factor analysed, except depth, showed temporal variation (Fig. 2), and salinity, pH, turbidity and depth showed significant spatial variation (Fig. 3). Interactions between months and sites, and between months, sites and years showed no significant differences in any abiotic parameter although much of the abiotic variation appeared to be related to seasonal (climatic) cycles. Interactions between months and years showed significant differences in pH ($p<0.001$) being higher in the second year at all sites, especially in spring. Interactions between sites and years showed a significant depth decrease ($p<0.001$) in the second year at most of sites (with the exception of the shallow sites - ARE, BAR and TOR).

Temperature varied from 27 ºC in summer to 7.6 ºC in winter (Fig. 2) and dissolved oxygen varied from hypoxic levels (4 $mg.l^{-1}$) in winter to oversaturated values (13 $mg.l^{-1}$) in summer. Salinity varied with distance from the mouth of the lagoon from typically freshwater (ARE and RIO), brackish water (VAG, LAR and CAR), and marine water (BAR, SJA, GAF and TOR) (Fig. 3). In areas less subject to the buffering activity of seawater, the pH varied between acid (6.81) in the regions with higher chemical pollution problems (LAR) (Fig. 1) (Pombo *et al*., 2000) and alkaline (9.62) in the regions with urban effluents and farming activities (Ílhavo channel, Vouga River and Ovar channel) (VAG, RIO and CAR) (Fig. 1). The turbidity, as shown by the light penetration depth, varied from 20 cm, at the edges during summer, to 2 m, near the mouth of the lagoon during winter (Figs. 2 and 3). Finally, the depth increased from the edges of channels (0.5 m) (ARE at south and TOR at north) to the deepest sites in the inner regions of the lagoon (6 m) (RIO, VAG and LAR) (Fig. 3).

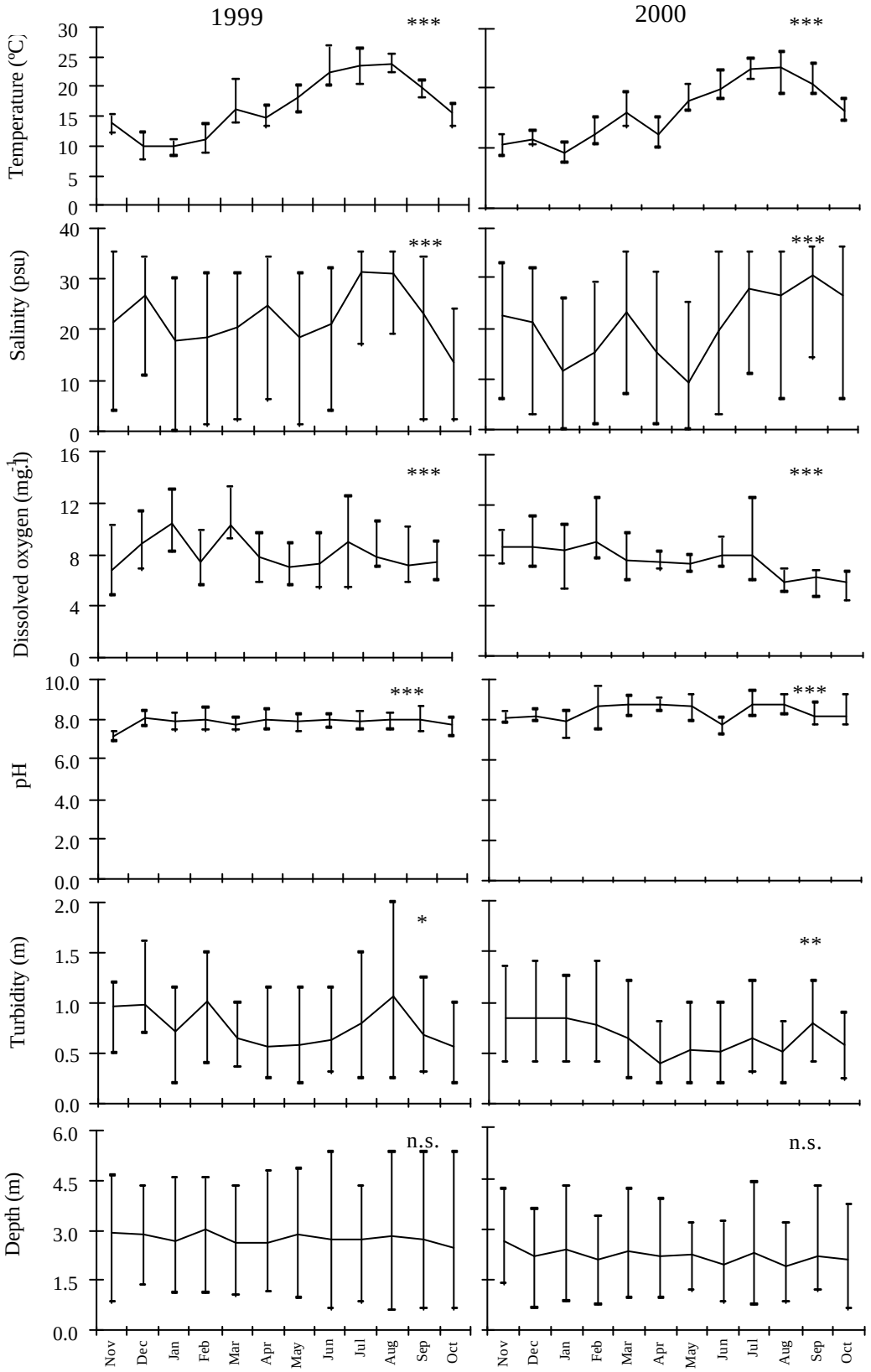

Fig. 2 - Minimum, average and maximum values of abiotic parameters by sampling months, in each year. Significantly differences of abiotic parameters between months are shown (*): p = 0.05, (**): 0.05 = p = 0.01; (***): p = 0.01; n.s.: p = 0.05.

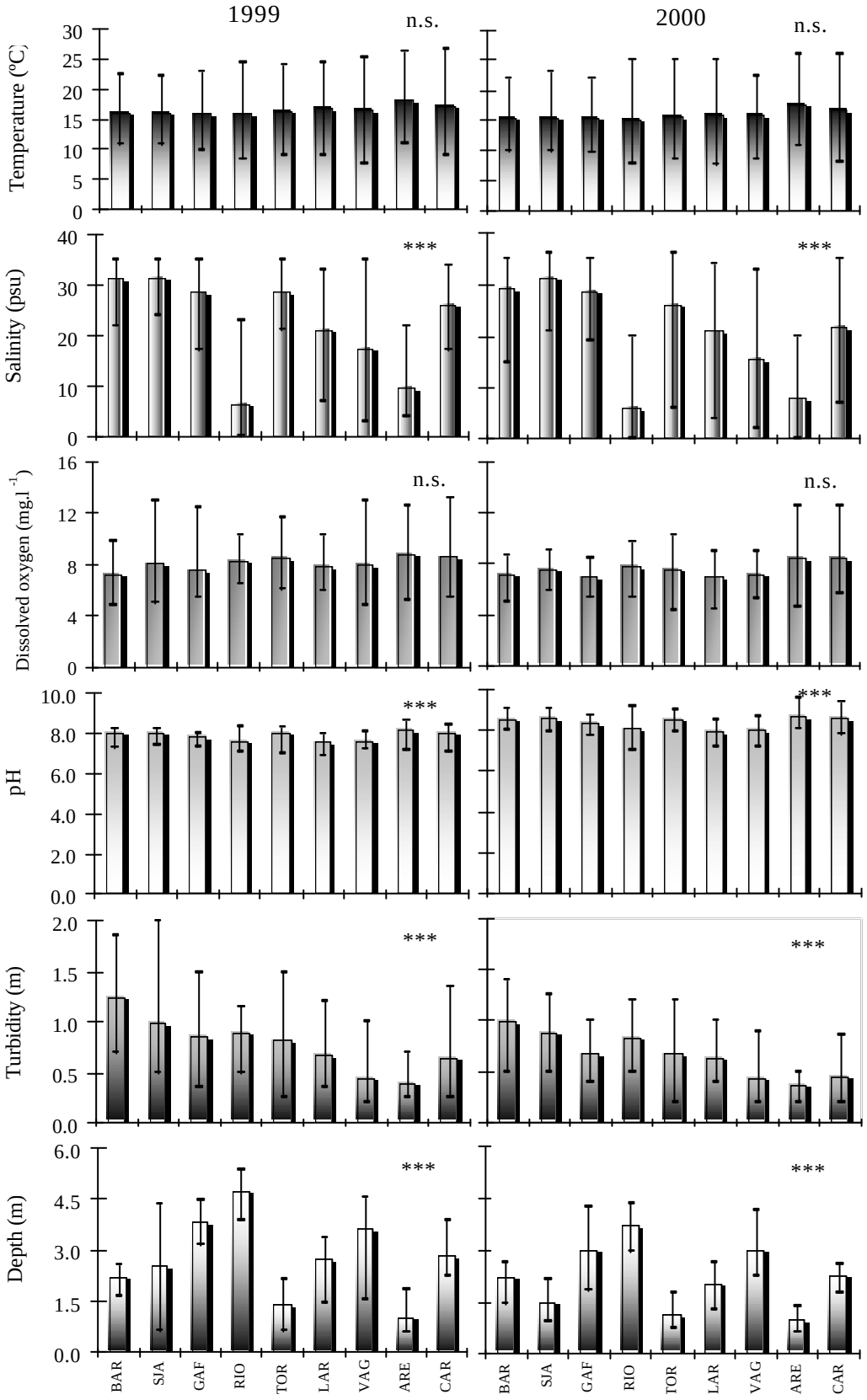

Fig. 3 - Minimum, average and maximum values of abiotic parameters by sampling sites, in each year. Site abbreviations are explained in the text and shown in figure 1. Significantly differences of abiotic parameters between sites are shown (*): p = 0.05, (**): 0.05 = p = 0.01; (***):p = 0.01; n.s.: p = 0.05.

Structure of the Fish Community

In this study 41,681 specimens comprised of 61 teleost species were captured, with a total biomass of 222 Kg (Table 1). Of the 61 species captured over the two years of sampling, only 33 species were common to both years, 20 species were exclusive to 1999 and 8 were exclusive to 2000 (Table 1). The decrease in number of species, from 1999 to 2000, was due to the absence in the second year of 10 marine adventitious visitors, 8 marine juvenile migrant species and 2 estuarine resident species (Table 2); however these were replaced by others in 2000: 3 marine adventitious, 2 freshwater, 1 estuarine resident, 1 marine juvenile, and 1 anadromous species.

Table 1 – Number of individuals, biomass and total number of species in the two years of sampling.

Total	**1999**	**2000**	**Total**
Number of individuals	19,424	22,257	41,681
Biomass (kg)	112.6	109.3	221.9
Samples species number			
Number of species	53	41	61
Exclusive species per year	20	8	
Common species in two years			33

Table 2 – Number of individuals and biomass (g) of fish sampled in 1999 and 2000 grouped by ecological guilds, according to Elliott & Dewailly (1995). Dominant species for CCA analysis are in bold.

		Abundance		Biomass (g)	
Species	Code name	1999	2000	1999	2000
Estuarine Resident Species					
Ammodytes tobianus	Atob	9	-	102.1	-
Aphia minuta	Amin	48	5	9.3	4.5
Atherina boyeri	**Aboy**	**2,082**	**2,911**	**5,624.7**	**3,074.2**
Gobius ater	Gate	1	4	9.4	54.0
Gobius niger	Gnig	182	235	2,732.5	3,026.8
Gobius paganellus	Gpag	18	2	189.4	13.4
Mugil cephalus	Mcep	8	5	2,457.0	2,056.7
Nerophis ophidion	Noph	1	-	3.0	-
Platichthys flesus	Pfle	121	21	988.5	250.7
Pomatoschistus microps	**Pmic**	**526**	**338**	**443.4**	**192.3**
Pomatoschistus minutus	Pmin	75	47	69.3	105.1
Symphodus melops	Smel	-	1	-	14.8
Syngnathus acus	Sacu	203	200	729.3	1,063.8
Syngnathus typhle	Styp	6	6	15.2	2.6
Marine Juvenile Migrant Species					
Atherina presbyter	**Apre**	**1,011**	**1,225**	**7,078.3**	**6,896.0**
Chelidonichthys lucerna	Cluc	202	32	4,569.9	977.0
Dicentrarchus labrax	**Dlab**	**37**	**757**	**1,456.0**	**7,954.5**
Dicentrarchus punctatus	Dpun	5	-	34.4	-
Diplodus annularis	Dann	2	-	14.9	-
Diplodus sargus	Dsar	20	5	94.3	30.3
Diplodus vulgaris	Dvul	4	-	155.3	-
Pleuronectes platessa	Ppla	1	-	0.1	-
Scophthalmus rhombus	Srho	-	3	-	18.7
Solea senegalensis	Ssen	6	-	96.0	-
Solea solea	Ssol	3	-	41.6	-
Spondyliosoma cantharus	Scan	1	-	89.2	-
Trisopterus luscus	Tlus	4	-	10.4	-
Marine Seasonal Migrant Species					
Chelon labrosus	Clab	140	14	1,846.2	757.4
Ciliata mustela	Cmus	22	6	139.3	212.6
Engraulis encrasicolus	Eenc	352	334	359.6	715.4
Liza aurata	**Laur**	**4,273**	**5,092**	**45,624.5**	**50,237.4**
Sardina pilchardus	**Spil**	**8,739**	**9,478**	**13,683.9**	**13,694.3**

		Abundance		Biomass (g)	
Species	Code name	1999	2000	1999	2000
Freshwater Adventitious Species					
Carassius carassius	Ccar	-	3	-	1,346.4
Gambusia affinis	Gaff	-	4	-	1.9
Marine Adventitious Visitors					
Balistes carolinensis	Bcar	1	-	379.4	-
Boops boops	Bboo	2	1	89.8	0.4
Callionymus lyra	Clyr	12	6	211.1	116.9
Conger conger	Ccon	1	-	0.6	-
Deltentosteus quadrimaculatus	Dqua	1	-	9.0	-
Echiichthys vipera	Evip	-	1	-	19.2
Entelurus aequoraeus	Eaeq	-	1	-	0.8
Hyperoplus lanceolatus	Hlan	1	-	2.6	-
Labrus bergylta	Lber	2	-	140.1	-
Labrus merula	Lmer	1	-	59.4	-
Mullus surmuletus	Msur	21	12	893.3	598.9
Parablennius gattorugine	Pgat	8	10	37.8	45.0
Parablennius sanguinolentus	Psan	1	-	7.6	-
Pomatoschistus marmoratus	Pmar	7	-	22.5	-
Psetta maxima	Pmax	1	-	49.4	-
Scomber scombrus	Ssco	1	-	19.2	-
Solea lascaris	Slas	11	2	55.3	24.1
Sparus aurata	Saur	-	8	-	97.4
Symphodus bailloni	**Sbai**	**93**	**159**	**1,421.3**	**1,417.5**
Symphodus cinereus	Scin	1	1	51.5	4.3
Trachurus trachurus	Ttra	8	5	112.3	56.3
Catadromous Migrant Species					
Anguilla anguilla	**Aang**	**53**	**46**	**2,690.2**	**2,031.8**
Anadromous Migrant Species					
Alosa alosa	Aalo	4	3	287.1	57.5
Alosa fallax	Afal	21	24	551.2	344.1
Gasterosteus aculeatus	Gacu	-	13	-	182.5
Liza ramada	**Lram**	**627**	**1,227**	**10,587.2**	**11,375.7**
Liza saliens	**Lsal**	**444**	**10**	**6,270.6**	**267.1**

The number of total individuals was slightly higher in 2000 (Table 1), although the biomass was similar in both years.

The marine seasonal (68%) and estuarine resident species (17%) accounted for 85% of total abundance and 67% of total biomass collected during the whole period (Table 2). Thirteen species were marine juvenile migrant species, comprising 8% of total numbers and 13% of total biomass. Twenty species were transient visitors to the lagoon, but they comprised a low number of the fish collected (1% of total individuals and 3% of total biomass). Only five species were anadromous and one catadromous accounting for 6% of total individuals and 13% of the total biomass. Only two freshwater species were collected and of these 7 individuals occurred sporadically in the lagoon (Table 2).

S. pilchardus was the most abundant species in both years, comprising 44% of total numbers and 12% of total biomass, followed by *Liza aurata* (Table 2). Marine seasonal species comprised 68% of total numbers and 57% of total biomass (Table 2). The next two most abundant species were the sand smelts, *Atherina boyeri* (resident) and *Atherina presbyter* (marine juvenile), which together accounted for about 17% of total numbers and 10% of total biomass (Table 2).

From the ten selected dominant species (represented in bold type in Table 2), six were present at every sampling site and three were evenly distributed in all seasons: *A. boyeri*, *A. presbyter*, and *L. aurata*. *Dicentrarchus labrax* occurred in larger numbers in summer and autumn, while *S. pilchardus*, *Liza ramada* and *Liza saliens* were more seasonal, being entirely absent or rare during winter and occurring in greatest numbers in spring, summer, and sometimes autumn.

There were no statistically significant interactions between months, sites, and years in the species richness. Species richness was significantly higher in 1999 than in 2000 ($p=0.003$), but in both years the number of species was consistently higher in spring-summer (from March to September ranging from 15 to 28 species) than in autumn-winter (from October to February ranging from 14 to 23 species) (Fig. 4). The increase in the number of species in spring and summer could be attributed to an influx of marine seasonal migrant species and marine juvenile species. Spatially, species richness showed no regular trend related to distance from the entrance of the lagoon (Fig. 4) and was higher in 2000 only at three

sampling sites (GAF, RIO and VAG) mostly due to the influx of marine adventitious species, but also marine seasonal species.

The indices of Shannon-Wiener diversity and evenness showed similar seasonal and spatial patterns each year during the study period (Figs. 5 and 6). The seasonal patterns for the two indices while similar varied depending on whether they were determined based on biomass or abundance (Figs. 5 and 6).

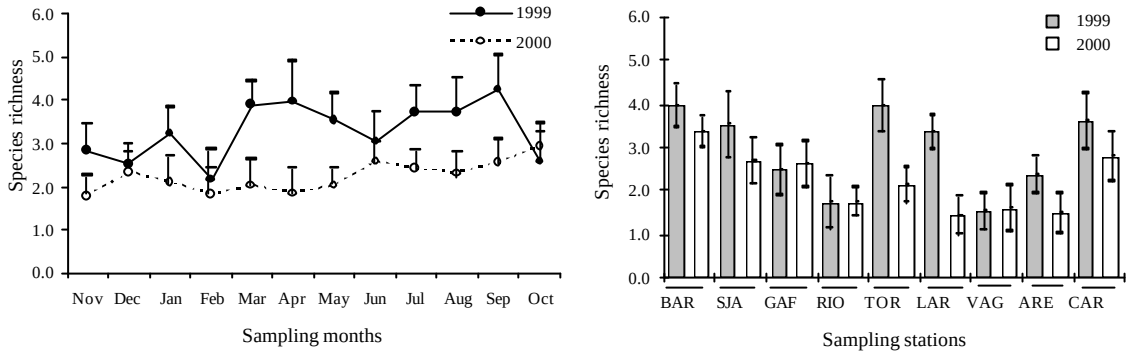

Fig. 4 - Species richness variation ± S.E., per month and sampling sites.

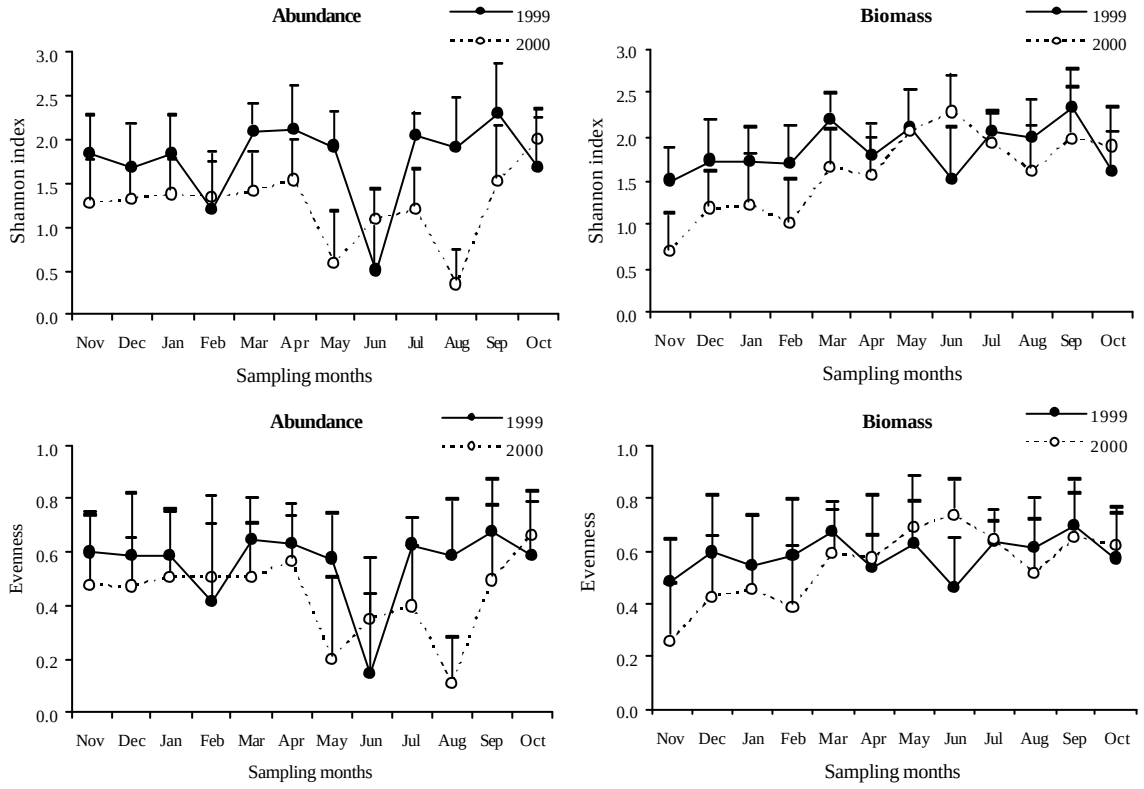

Fig. 5 - Shannon and Evenness indices variation + S.E., per sampling months, by abundance and biomass for each year.

Any interactions between months, sites, and years showed no significant difference in the Shannon-Wiener diversity and evenness indices. The indices, while showing similar seasonal patterns, were significantly different between years ($p=0.008$ for Shannon-Wiener, $p=0.012$ for evenness), with 1999 being higher than 2000 (Figs. 5 and 6).

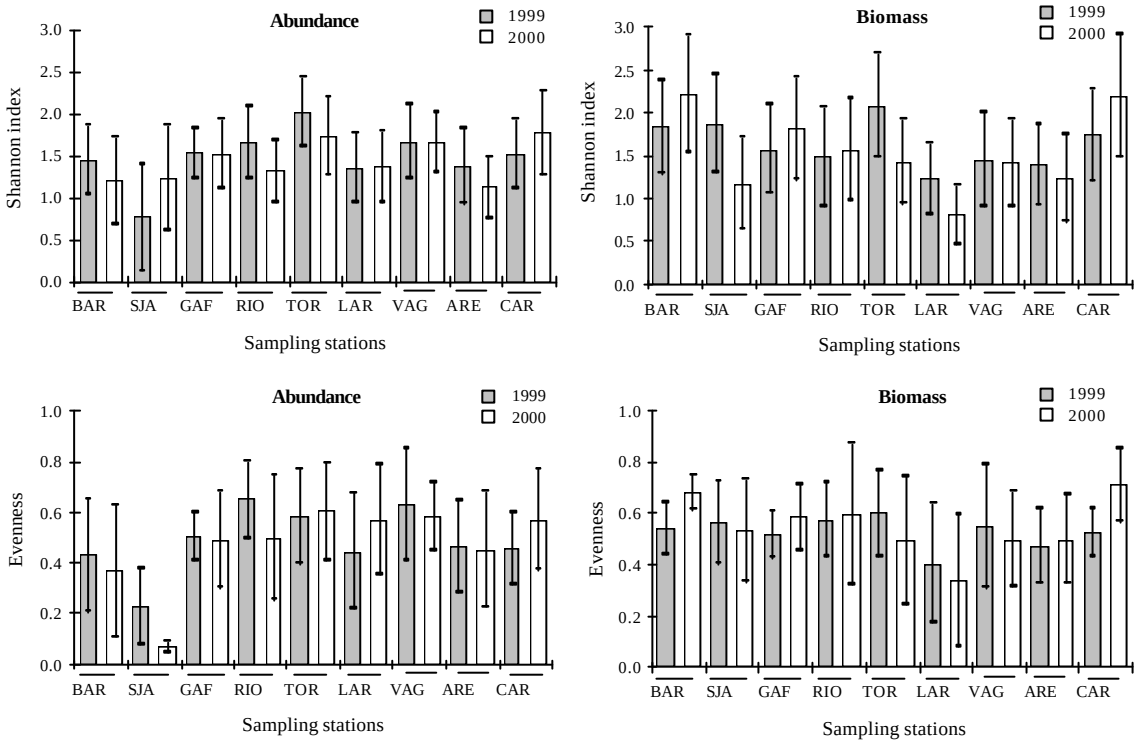

Fig. 6 - Shannon and Evenness indices variation ± S.E., per sampling sites, by abundance and biomass for each year.

Spatially, the Shannon-Wiener diversity and evenness were not significantly different between years at any sites. Shannon-Wiener diversity and evenness were higher in spring and autumn, in terms of abundance, and were lower in May, June and August (Fig. 5). The May-August periods corresponded to the large recruitment of a marine seasonal migrant species, *S. pilchardus*. The capture of this species in June 1999 corresponded to 34% of total abundance, and in May and August 2000, 13% and 9%, respectively. This resulted in the lowest values of the diversity index and evenness being observed during these periods. In terms of biomass, specimens of *S. pilchardus* that recruit to the lagoon are small juveniles with a mean length of 5.2 cm and a mean weight of 1.5 g. Spatially, diversity and evenness, determined from abundance data, was higher in the intermediate

regions than at the mouth area of the lagoon (Fig. 6). The diversity index calculated according to biomass was higher at intermediate regions and the regions near the mouth of the lagoon in 1999, and at the northern site in 2000, where the occurrence of adult *L. ramada* and *L. aurata* was high (Fig. 6).

The MDS ordination and cluster analyses (Figs. 7 and 9) showed that the fish assemblages were distinct between cooler, intermediate and warmer seasons.

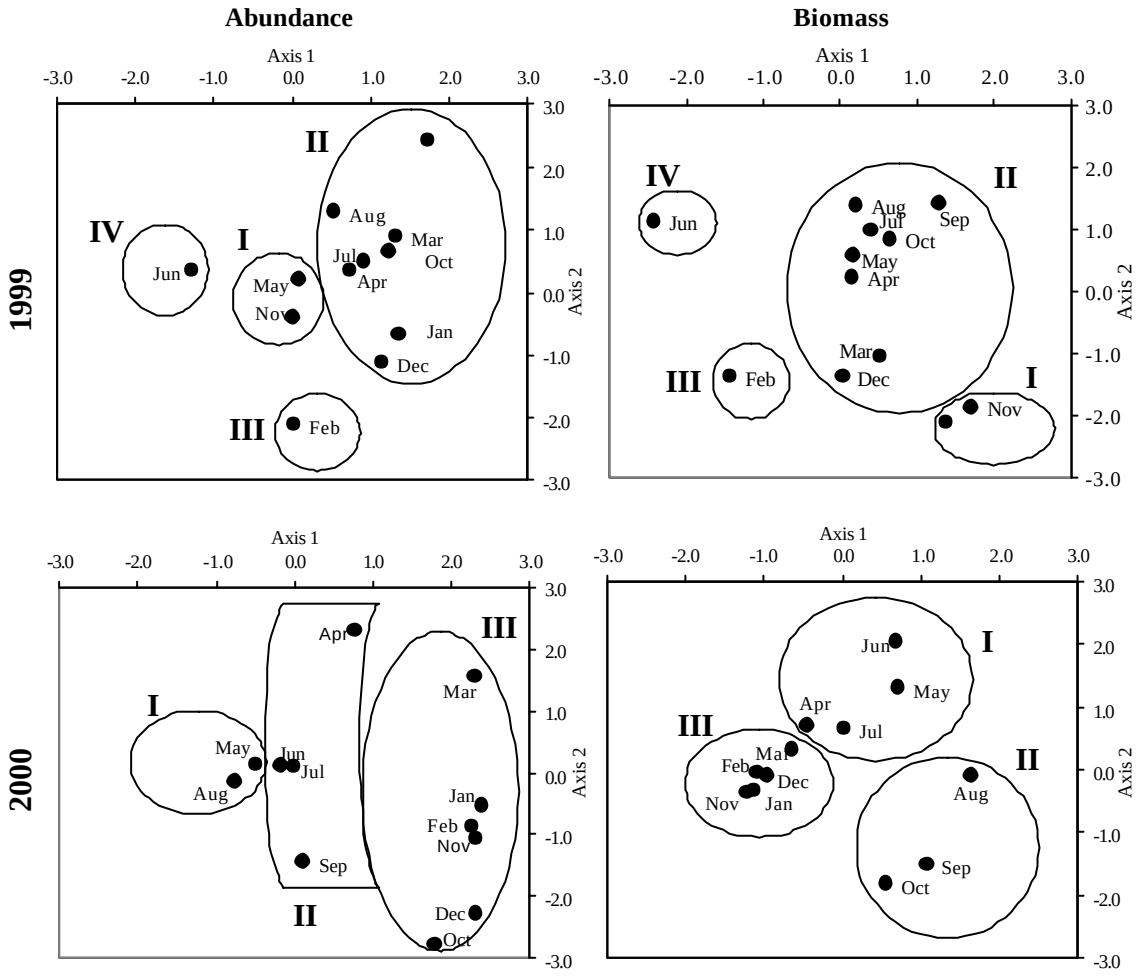

Fig. 7 - Multi-dimensional scaling (MDS) ordination of fish abundance and biomass collected in each sampling month for each year. Clusters are produced after Bray-Curtis similarity analyses (52% and 55% of similarity are the levels of which each fusion occurs, for abundance and biomass, respectively).

Fish abundance collected from the cooler seasons (winter) were positioned on the right upper (in 1999) and lower (in 2000) of the MDS 2-dimensional plot, and those collected from the warmer seasons (summer) were positioned on the left of the plot, and from the intermediate seasons were positioned in the middle of the plot.

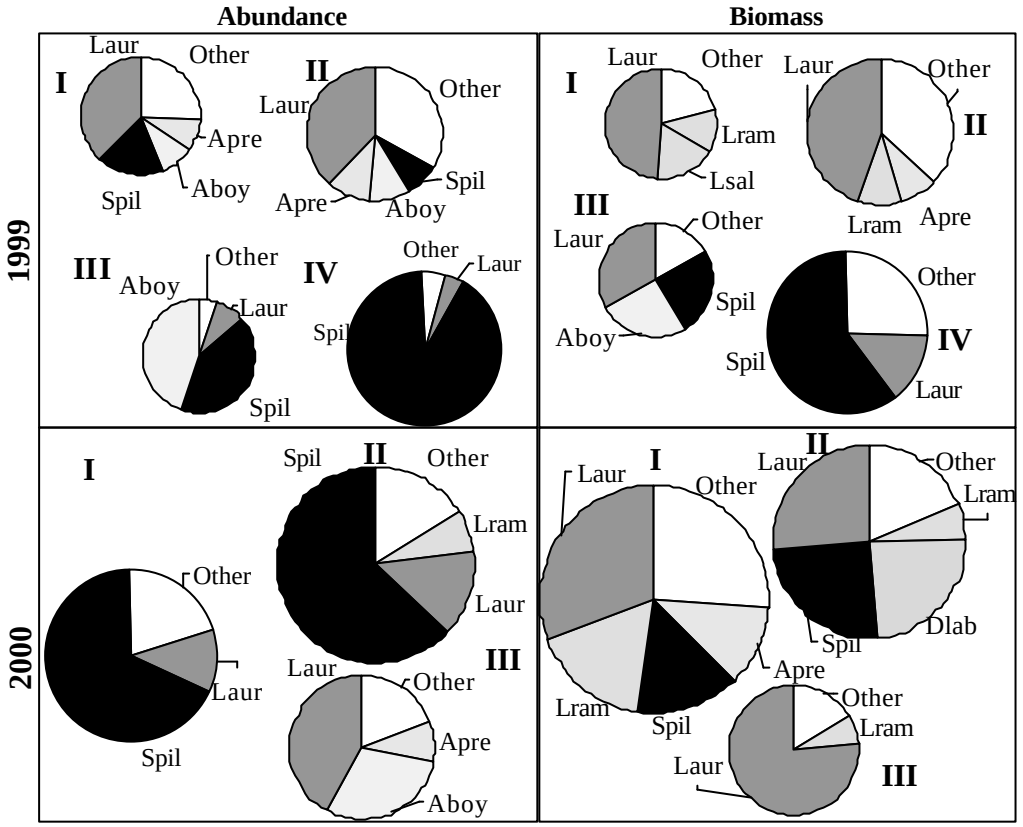

Fig. 8 - Pie charts of fish abundance and biomass for each year resulting from sampling clusters produced in fig. 9. The size of each pie is proportional to the number of samples comprising the assemblage. Species code names are provided in table 2.

Fish biomass collected from the cooler, warmer and intermediate seasons showed a slightly different distribution within the plot. Fish collected from the cooler seasons were positioned on the right lower (in 1999) and left (in 2000) of the MDS 2-dimensional plot, and those collected from the warmer seasons were positioned on the left of the plot (in 1999) and in the mid-upper (in 2000), and from the intermediate seasons were positioned in the middle of the plot.

For abundance data, the dominant axis 1, which accounted for 54% in 1999 and 77.3% in 2000 of the observed variation by all axes, had an eigenvalue of 0.52 in 1999 and 2000 and separated the groups seasonally, while axis 2 had an eigenvalue of only 0.18 in 1999 and 0.06 in 2000 and accounted for 14% in 1999 and 6% in 2000 of the four axes. Axes 3 and 4 accounted for little of the remaining variation and were not assessed further. The same trend was observed for the biomass data.

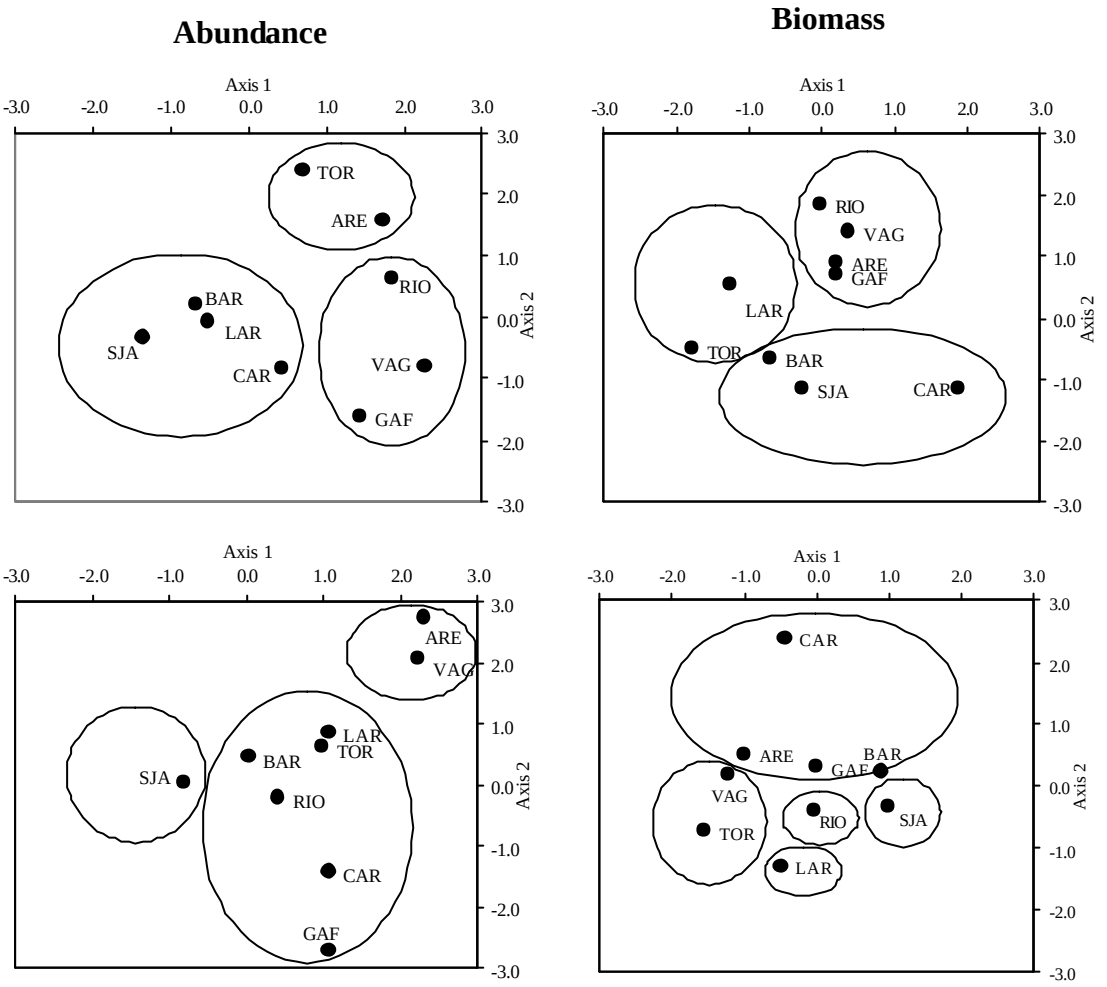

Fig. 9 - Multi-dimensional scaling (MDS) ordination of fish abundance and biomass collected in each sampling site for each year. Clusters are produced after Bray-Curtis similarity analyses (40% and 52% of similarity are the levels of which each fusion occurs, for abundance and biomass, respectively).

For the site groupings determined from the MDS ordination (Fig. 9), fish abundance collected from the lagoon edges were positioned on the right upper (in 1999 and 2000) of the plot, whereas those collected from inner sites were positioned in the middle of the plot, and from the mouth of the lagoon were positioned in the left of the plot. For the fish biomass, those samples collected from the edges were positioned on the right (in 1999) and mid-upper (in 2000) of the plot, and those collected from the inner sites were positioned on the left of the plot (in 1999) and in the mid-lower (in 2000), whereas those from the mouth of the lagoon were positioned in the mid-lower (in 1999) and in the right side (in 2000).

The results of the pie charts paralleled those produced by the cluster analysis and showed that fish assemblages were distinct between years with respect to abundance or biomass (Figs. 8 and 10). The presence and abundance of *S. pilchardus* and *L. aurata* were the most important features differentiating amongst the clusters.

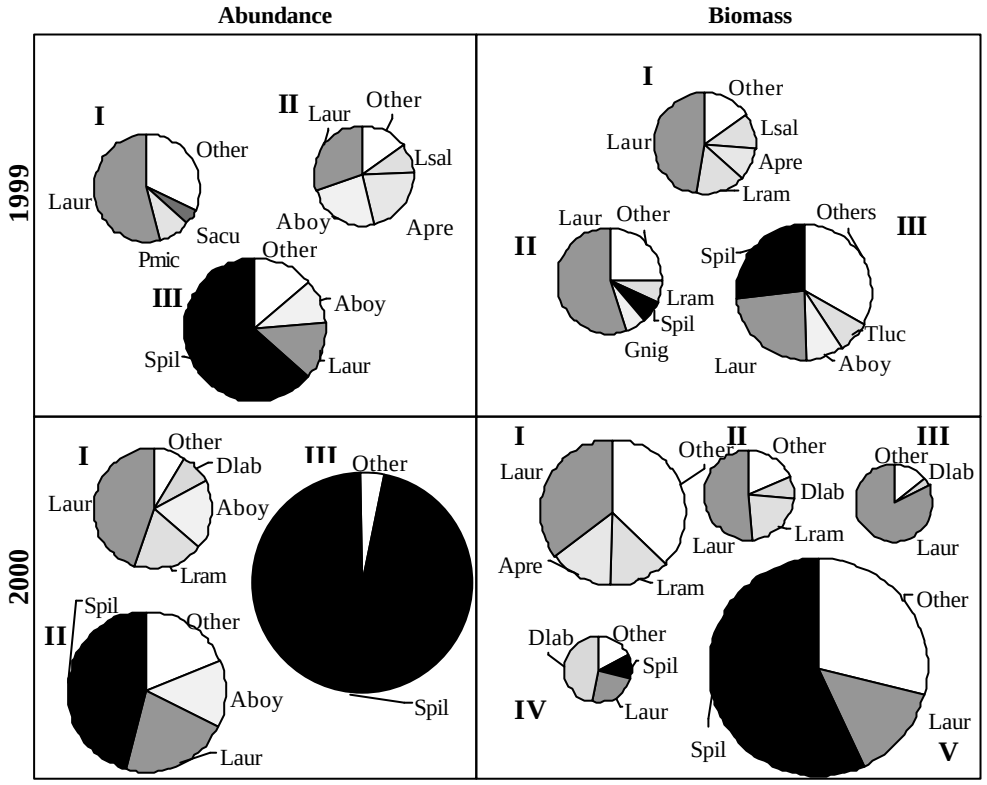

Fig. 10 – Pie charts of fish abundance and biomass for each year resulting from sampling clusters produced in fig. 7. The size of each pie is proportional to the number of samples comprising the assemblage. Species code names are provided in table 2.

The classification of the monthly abundance samples distinguished four groups in 1999 and three groups in 2000 at the 50% level of Bray-Curtis similarity. Over the whole year there was a diverse assemblage, dominated by either *L. aurata* (more than 38%, cluster I and II) or *S. pilchardus* (41% in the cluster III and 91% in the cluster IV) (Fig. 8). The February assemblage (cluster III) was strongly dominated by *A. boyeri* (45%) with large components of *S. pilchardus* (41%) and the June assemblage (cluster IV) was highly dominated by *S. pilchardus* (91%) (7225 individuals). Cluster I in 2000 (7171 individuals), included only two months (May and August) and was strongly dominated by *S. pilchardus* (68%). Cluster II

was composed of the largest group of individuals (10336) and included four months encompassing spring and summer. This group was dominated by *S. pilchardus* (63%) but *L. ramada* (16%) and *L. aurata* (14%) also contributed. Cluster III (6740 individuals) was composed of 6 months dominated by *L. aurata* (42%) and *A. boyeri* (30%).

In terms of biomass, similar clusters were produced in both years, although *S. pilchardus* showed less contribution for the production of clusters because of its low biomass comparing to *L. aurata*, whose biomass was the highest in most clusters (Fig. 8). Only in June (the cluster IV of 1999) was the biomass of *L. aurata* (14%) lower than the biomass of *S. pilchardus* that reached 6.6 Kg representing more than 60% of total biomass.

Cluster analysis of species abundance data from the different sites distinguished three groups in 1999 and 2000 at the 40% level of Bray-Curtis similarity (Fig. 9). Assemblages I (the middle of the main channel and the southern channel) and II (the inner and southeast sites), although showing different diversity, were both strongly dominated by *L. aurata* (Fig. 10). Cluster III included the greatest number of individuals (13508), but was clearly dominated by *S. pilchardus* (64%). In 2000, cluster I included only two sites (the two southern sites), was strongly dominated by *L. aurata* and displayed the greatest diversity. Cluster II was comprised of the largest group of individuals (15693), included six sites and was dominated by *S. pilchardus*, but also *L. aurata*, *A. boyeri* and others. Cluster III, was comprised of only one site (near the mouth of the lagoon), and was dominated by *S. pilchardus* (74%).

In terms of biomass, for 1999, the assemblages I and II were strongly dominated by *L. aurata* (48% in cluster I and 55% in cluster II) (Fig. 10). Both represented assemblages of moderate to high abundance and diversity. Assemblage III was dominated by other secondary components (33%), *S. pilchardus* (27%) and *L. aurata* (24%), representing the largest group of individuals (10893) and a high diversity of species. The biomass assemblage in 2000 varied considerably, but the largest component was usually *L. aurata* (clusters I, II and III). Assemblage IV was unusual in its dominance of *D. labrax* (47%), representing the smallest number of individuals (1134 samples). In comparison, assemblage V

was the largest (9478 individuals), dominated by *S. pilchardus* (57%) and displayed a high diversity.

Environmental Influences on Fish Distribution

The relative importance of the measured environmental factors to the dominant fish species are shown in figure 11, for abundance, and figure 12, for biomass (as determined by the environmental variable vectors within the canonical correspondence analyses). Although four axes were determined within each analysis, only axes 1 and 2 were plotted as they accounted for 82% and 80% of the variability explained by the four axes, respectively in each year, for the abundance data; and 71% and 81% in each year, for the biomass data.

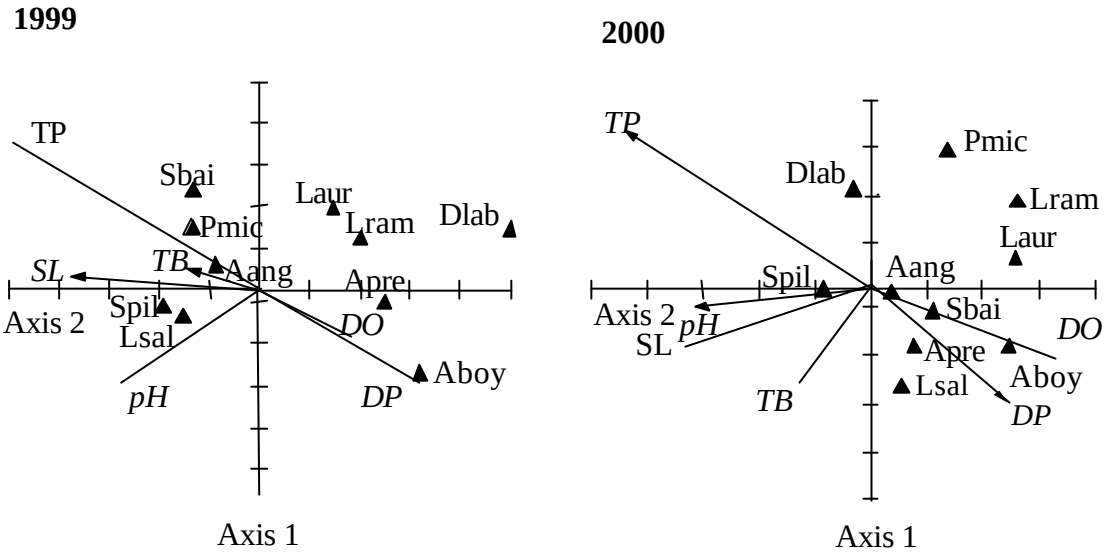

Fig. 11 - CCA ordination diagram of dominant fish abundance with environmental factors represented by vectors: temperature (TP); salinity (SL); dissolved oxygen (DO); pH (pH); turbidity (TB) and depth (DP). Species code names are provided in table 2. Axis 1 and 2 accounted for 43% and 34% of the variability explained, respectively, in 1999, and for 44% and 36% in 2000.

The relative lengths of the vectors indicate that temperature was the most important abiotic factor explaining the distribution and abundance of species (Fig. 11). Temperature variation reflected the seasonally varying nature of the assemblage and proved to be the best predictor of total abundance and species richness. Pearson correlations indicated that temperature, salinity and pH correlated positively with species richness and depth correlated negatively with species richness (Table 3).

Table 3 - The degree of correlation between species richness and diversity indices and abiotic factors. TP: temperature; SL: salinity; DO: dissolved oxygen; pH: pH; TB: turbidity; DP: depth. (n.s.): p > 0.05; (+ or -): 0.05 = p > 0.01; (++ or --): 0.01 = p > 0.001; (+++ or ---): p < 0.001.

	1999						2000					
	TP	SL	DO	pH	TB	DP	TP	SL	DO	pH	TB	DP
Species Richness	++	+++	n.s.	++	n.s.	---	+++	+++	++	++	n.s.	-
Shannon (Abundance)	n.s.	+++	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.
Evenness (Abundance)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Shannon (Biomass)	+	+++	n.s.	+	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.
Evenness (Biomass)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Salinity also correlated positively with the Shannon-Weiner index in both years. The number of species was higher and the majority of species occurred in higher abundance at above average temperature and salinity (spring and summer) (Figs. 2, 4 and 5), near the mouth of the lagoon, where salinity was high and at the edges of the lagoon, where depth was low (Figs. 3, 4 and 6). As also shown by the position of the CCA environmental variable vectors, temperature was correlated with abundance of *A. anguilla* in the first year, and *S. pilchardus* and *D. labrax* in the second year, and negatively correlated to *L. ramada* in the second year.

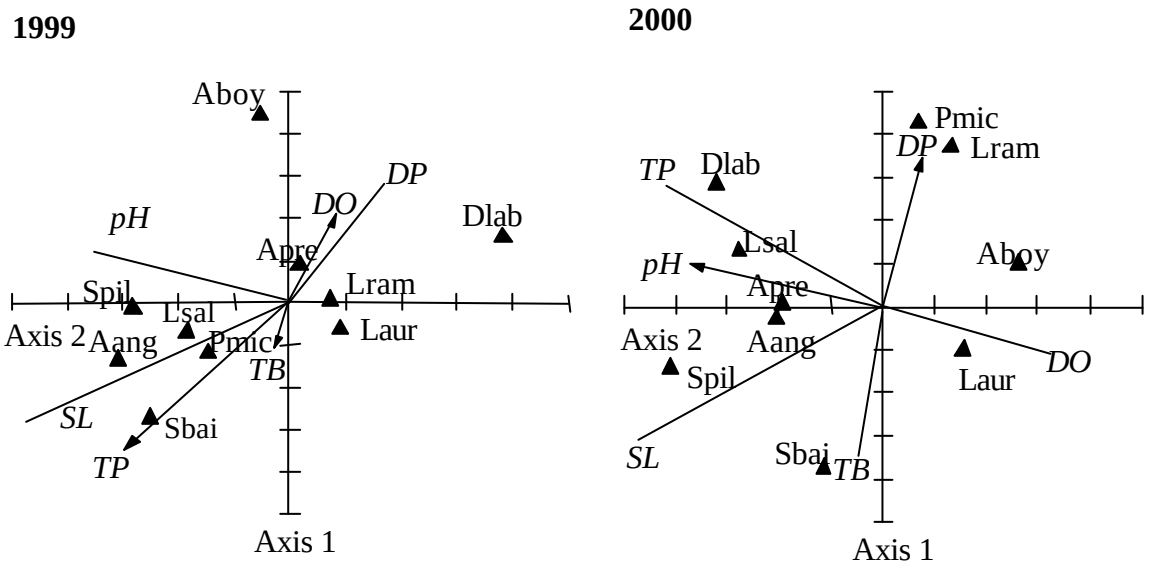

Fig. 12 - CCA ordination diagram of Ria de Aveiro dominant fish biomass with environmental factors represented by vectors: temperature (TP); salinity (SL); dissolved oxygen (DO); pH (pH); turbidity (TB) and depth (DP). Species code names are provided in table 2. Axis 1 and 2 accounted for 42% and 30% of the variability explained, respectively, in 1999, and for 50% and 31% in 2000.

Analysis of the biomass data (Fig. 12) gave a slightly different grouping of species with respect to the environmental variables and the relative importance of variables also differed. Salinity was found to be the most important abiotic factor explaining the fish biomass, with temperature and pH also explaining some of the distribution of fish biomass being positively correlating with Shannon-Weiner index (Table 3). Biomass of dominant species was higher in summer, near the mouth of the lagoon, in the middle of the main channel and the inner channel, where high salinity levels occurred (Figs. 3, 4 and 6). Salinity and temperature positively correlated to *S. pilchardus* and *A. anguilla* in both years (Fig. 12), which occurred with high biomass near the mouth of the lagoon and in the middle of the main channel with high salinity, especially in summer, with high temperature.

The nature of CCA dictates that any species highly correlated with two variables will be positioned along the axis created by two vectors rather than at the end of any single vector (Ter Braak, 1988). Thus, the positions of depth, turbidity, and dissolved oxygen vectors may result in a skewing of the species distribution.

Discussion

Fish studies are important in estuarine water quality evaluation and assessments of human impacts (Elliott *et al*., 1988; Elliott & Hemingway 2002) and both fish abundance and species diversity can provide managers with an indication of the health of a particular system (Whitfield, 1996). They indicate the nature of the area, the effects of anthopogenic influences and the efficacy of management actions although an interpretation of these aspects requires a knowledge of the fish biology in relation to environmental changes. This is particularly true of highly variable systems such as the Ria de Aveiro in which, as shown here and elsewhere, the distribution and abundance of fish was related to three broad factors: life-history patterns, environmental variation, particularly water temperature and salinity, and variation in habitat characteristics (depth).

Life History Patterns

The estuarine coastal lagoon, Ria de Aveiro, comprises the usual components of an estuarine fish assemblage, including residents, nursery, and

seasonal, juvenile and diadromous migratory types. According to the definition of estuarine resident species and marine juvenile migrant species (Elliott & Dewailly, 1995), *A. boyeri* and *P. microps*, which were confined to the inner region and edges of the lagoon, were considered to be estuarine dependent during all their life cycle. The species, *A. presbyter* and *D. labrax*, were considered estuarine dependent only in the juvenile phase, and marine seasonal species included juveniles of *S. pilchardus* and *L. aurata*. The presence, abundance and biomass of *S. pilchardus* were important determinants of the dynamics and structure of the lagoon's fish assemblages. Because these estuarine opportunistic species are found at various times throughout the lagoon systems, they are considered to be appropriate indicators of natural or anthropogenic change in lagoons and estuaries (Pombo & Rebelo, 2002). Although the number of marine seasonal species was low, their abundance and biomass were very high. The opposite occurred with the marine adventitious species with high number of species but low abundance and biomass, hence the term adventitious. Diadromous (catadromous or anadromous) migrant species, which use the lagoon to pass between salt and freshwater for spawning and feeding, included *A. Anguilla* (a traditional and economically important species for the region), *L. ramada* and *L. saliens* (some of the largest collected specimens). Freshwater species, which were very rare, entered occasionally to the lagoon with no apparent estuarine requirements.

Relationships between Environment and Fish Assemblages

The Ria de Aveiro, similar to other coastal estuarine lagoons (Leeuwen *et al*., 1994; Elliott & Hemingway, 2002), is a system highly influenced by abiotic variations, which affect the recruitment and the survival of fish species (Rebelo, 1992; Pombo & Rebelo, 2002). Temperature was found to be the most important abiotic factor affecting the abundance and distribution of fish species and proved to be the best predictor of total abundance. Variation in abundance within the lagoon was more related to seasonal migrations rather than to spatial migrations within the lagoon. Similar results have been observed in other regions of the world (Thiel *et al*., 1995; Jones *et al*., 1996; Marshall & Elliott, 1998; Kuo *et al*., 2001). The ichthyofauna of the lagoon varied in response to temperature, with major

differences observed between spring-summer and autumn-winter. For the warmer spring-summer period, where average temperatures were above 15ºC, the fish abundance and number of species were high over the whole lagoon. During the cooler autumn-winter period, most of the dominant species decreased in abundance markedly and occurred in greater abundance at the areas near the mouth of the lagoon. This was particularly the case for the adventitious and seasonal migrant species.

S. pilchardus consistently contributed to the low values in the diversity parameters, particularly in May, June and August. *S. pilchardus* recruits to the lagoon at less than one year of age (Rebelo, 1992), between April and July, with highest abundance in May and its density was highest at the mouth regions. The variation in species diversity was mainly due to the frequently occurring species, those abundant species which are characteristic of the lagoon, and are responsible for the fish productivity of this lagoon system. Although the biomass (113 and 110 Kg wet weight, respectively in each year) was similar in both years, the abundance was slightly higher in the second year (19,424 and 22,257 individuals in the first and second year, respectively). This is due to the large migration into the lagoon of juvenile (small individuals with a low biomass) of *S. pilchardus*. These small juveniles however did not result in a high total biomass.

Many studies (Thiel *et al*., 1995; Thorman, 1986; Marshall & Elliott, 1998) have indicated that salinity is an important factor in influencing the distribution and abundance of fish in estuaries, particularly those with significant freshwater influx (Loneragan & Potter, 1990). In the present study and in the Humber estuary (Marshall & Elliott, 1998) variation in temperature and salinity was related to variation in different aspects of the fish community, with more species apparently affected by salinity changes than temperature variation. Salinity significantly varied seasonally and spatially between 0 and 35 psu, decreasing gradually towards the upper reaches of the channels with a significant freshwater inflow, but in some remote shallow areas the circulation was reduced and increased salt concentration occurred during the summer. The lack of statistical interactions between sites and months indicates that much of the variations appeared related to seasonal climate cycles, such as rainfall. At times of maximum freshwater discharge resulting from

continued rainy periods, as occurred in 2000, the salinity decreased significantly all over the lagoon.

The biomass distributions were also affected by the movements of fish within the lagoon. These migrations modified the distribution of the ichthyofauna, especially the benthic fish, which migrate to deeper regions, possibly as a strategy for protection against predators and to minimize food competition with others fish species (Harley *et al*., 2001). The low salinity, particularly between March and May, due to the continued rainy periods in the second year of sampling, will influence the distribution of fish mainly through their salinity tolerance. Thus, in some cases, low salinity may act as a barrier to penetration by stenohaline marine species; therefore the number of species was much lower in the second year of sampling during the reduced salinity periods. Similar patterns were observed in the Bothnian Sea (Thorman, 1986) with positive correlations between minimum salinity and average species number. However, in many cases, the range of salinity at which fish are habitually found is much narrower than their tolerance range. In addition, the response of many species to salinity may vary with life stage (Kuo *et al*., 2001).

Correlations between the other environmental factors and assemblage structure were identified. Dissolved oxygen showed a similar trend to salinity also importantly explaining variation in the distribution of fish species; it is of note that water quality barriers, through the production of low oxygen zones, have influenced community structure in many estuarine areas (Elliott & Hemingway, 2002) and low levels could affect the species composition through the tolerance limits of the different species. Dissolved oxygen and depth influenced most species in the second year, when both factors decreased. Thus, in the second year, *A. boyeri* was not so abundant at the northern edges and occurred mainly at the Ílhavo channel, at the south, where dissolved oxygen was higher. In the first year, *D. labrax* was abundant at the inner site, and in the second year this species mainly colonized the edges of the lagoon, the Ovar channel, to the north, and Ílhavo channel, to the south, where dissolved oxygen was lower. In this study, it was notable that the abundance of sea bass increased more than 20 times from one year to another, and it is possible that the low dissolved oxygen may have

been related to this occurrence; however, other factors that were not controlled in this study, such as food supply, overfishing or currents direction, will also have influenced the presence of the species.

The relationship between pH and the abundance and biomass of *A. anguilla* was strong in the first year but, when pH significantly increased in the second year, the relationship was not significant. In the first year, this species occurred mainly in the main channel, where pH was basic-alkaline but in the second year, when the pH values increased in the lagoon, the species moved towards the mouth, where more alkaline values persisted. The interactions between month and year for pH factor, and between site and year for the depth factor, indicate that these two parameters may have an important influence on fish assemblage. Species richness was positively correlated with pH, while depth was negatively correlated with species richness. However, it is possible that these correlations are due to co-variance with third factors such as salinity (freshwater discharge).

The importance of turbidity has been attributed to providing either protection from visual predators or an increased food supply (Marshall & Elliott, 1998). In this study, turbidity did not have a significant relationship with species richness or diversity indices. This is evident in the CA plot, where the turbidity vector was the smallest.

This study constitutes a baseline for future studies both within the lagoon and elsewhere is transitional water bodies. In particular, it shows the importance of showing the inter-relationships between the biotic (fish) and abiotic factors. Although it is difficult to separate and analyse separately each environmental factor from the others, it is known that they interact with each other. There are other environmental factors that were not monitored in this study and that are likely to have an influence on fish distribution, namely the tides, current velocity, streams, and human impacts, as fishing (Marshall & Elliott, 1996, 1998). Several natural and anthropogenic factors may have a direct influence on the environmental and therefore on food resources, distribution, abundance, growth, survival and behaviour of the fish present (Whitfield, 1996). In addition, for a complete understanding of lagoonal fish ecology, it is necessary to determine the

biological relationships superimposed on those environmental relationships, for example predator-prey and competition interactions.

In recent decades, there has been an increasing concern about man's impact on the ecosystem (Van Leeuwen *et al*., 1994). The marine environment may potentially be affected by a variety of human activities, both direct and indirect, including coastal engineering works, pollution, eutrophication, fisheries and global warming. Dredging of the Ria de Aveiro occurred in the years prior to this study (between October 1997 and May 1998) and included extracting a total of 1,510,000 m^3 of sediment from the main channels (Ovar, Murtosa, and Mira) (JAPA, 1993). This increased the tidal-range and water exchange (JAPA, 1993), possibly allowing a large variety of marine adventitious species to enter the lagoon. In particular, deepening of channels may provide greater potential for water column species (JAPA, 1993), particularly marine species, to enter from the adjacent coastal zone.

Other possible indirect factors such as fluctuations in tide levels, and current velocity and direction may influence the fish communities (Jones *et al*., 1996). The aggregation of lagoon-opportunistic and lagoon-dependent species in smaller areas may increase vulnerability of populations to a number of environmental and human perturbations such as point-source pollution (organic and chemical spills), toxic algal blooms or seasonally heavy fishing intensity (Jones *et al*., 1996). However, the relatively high levels of oxygen and the presence of a varied ichthyofauna indicate that the adopted environmental quality objectives (EQO) are being fulfilled (Marshall & Elliott, 1996).

The increasing fishing effort as a result of the leisure and commercial fishing has not been quantified in the Ria de Aveiro, but there is circumstantial evidence to suggest that it has increased for some species, mainly *Solea solea*, *Platichthys flesus*, *A*. *anguilla* and *D. labrax*. Another consequence of fishing is a decrease in the potential nursery area for estuary-opportunistic species in the inner estuary during warmer months, so in the years of high recruitment to the lagoon survival rate of new recruits could be adversely affected. It is also possible that a change in the predator-prey relationship may occur in the lagoon affected area. Further studies are required on trophic relationships between species and on production

studies to better predict how this factor may influence the fish community structure.

The Ria de Aveiro shows a dynamic and a variable environment, like other transitional water bodies, with significant variations in the abiotic and physical parameters of the water. These environmental variations appear to be an important influence on the distribution and diversity of the ichthyofauna, with strong seasonal patterns observed by our study. Despite the vulnerability of this system, the Ria de Aveiro exhibits a predictable spatial and temporal pattern of fish biomass and diversity.

Acknowledgements

The authors would like to thank the University of Aveiro, the Foundation for Science and Technology and the European Social Fund that financially supported this study. The authors are also very grateful to all the students who helped in the field and laboratory work. We also thank the referees of this review for the revision and constructive comments of the manuscript.

References

Alcolado, P.M. 1996. Controversia sobre la relación entre la diversidad de especies y la estabilidad de las comunidades. *Avicennia*, 4/5: 13-26.

Arruda, L.M.; Andrade J.P. & Cunha, M.M. 1988. Abundance, diversity and community structure of the fish population in the Ria de Aveiro (Portugal). *Oceanol. Acta*, 11 (3): 235-240.

Barrosa, J.O. 1980. A Ria de Aveiro e a sua influência na economia da região. *Recurs. Hídric.*, 1 (3): 83-96.

Bauchot, M.L. & Pras, A. 1987. *Guía de los peces de mar de España y de Europa.* Ediciones Ómega, Barcelona.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. *Spec. Sci. Rep*. No.77.

Borrego, C.; Cruz, M.M. & Gonçalves, P. 1994. *Estudo de avaliação da vulnerabilidade da capacidade de recepção das águas costeiras em Portugal. Relatório R 3.2. Meios receptores e suas características: (Be 1) - Ria de Aveiro, Pateira de Fermentelos e Barrinha de Mira.* Projecto nº 13/94. IDAD, Aveiro.

Elliott, M. & Dewailly, F. 1995. The structure and components of European estuarine fish assemblages. *Neth. J. Aquac. Ecol*., 29 (3-4): 397-417.

Elliott, M. & Hemingway, K. L. (Eds.) 2002. *Fishes in Estuaries.* Blackwell Science, Oxford.

Elliott, M.; Griffiths, A.H. & Taylor, C.J.L. 1988. The role of fish studies in estuarine pollution assessment. *J. Fish Biol.,* 33 (Supplement A): 51-61.

Hall, A. 1980. Water quality problems in Ria de Aveiro. A preliminary assessment. In: Seminar on actual problems of Oceanography in Portugal, Lisboa, 20-21 Nov., 1980: 159-169.

Harley, X. ; Koubbi, P. & Grioche, A. 2001. Ecology of plaice (*Pleuronectes platessa*) in fish assemblages of beaches of the Opale coast (North of France) during spring 1977. *Cybium*, 25 (1): 67-80.

Hill, M.O. 1973. Diversity and evenness: A unifying notation and its consequences. *Ecologie*, 54: 427-432.

James, E.M.Jr. 2001. Biological structure and dynamics of littoral fish assemblages in the Eastern Finger Lakes. *Aquat. Ecosyst. Health Manage.Soc.*, 4: 91-115.

JAPA. 1993. *Estudo de impacto ambiental – desassoreamento da Ria de Aveiro, 1ª fase*. Junta Autónoma do Porto de Aveiro. Edição do Porto de Aveiro, Aveiro.

Jones, G.K.; Baker, J.L.; Edyvane, K. & Wright, G.J. 1996. Nearshore fish community of the Port River-Baker Inlet Estuary, South Australia. I. Effect of the thermal effluent on the fish community structure, and distribution and growth of economically important fish species. *Mar. Freshwater Res.*, 47: 785-99.

Jongman, R.H.G.; ter Braak, C.J.F. & van Tongeren, O.F.R. 1995. *Data analysis in community and landscape ecology. Ch. 5 Ordination.* Cambridge University Press, New York.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries*, 6: 21-27.

Kovack. 1998. *MVSP version 3.01*. Copyright Kovack Computing Services, U.K.

Kuo, S-R.; Lin, H-J. & Shao, K-T. 2001. Seasonal changes in abundance and composition of the fish assemblage in Chiku lagoon, Southwestern Taiwan. *Bull. Mar. Sci.*, 68 (1): 85-99.

Leeuwen, P.I. van; Rijnsdorp, A.D. & Vingerhoed, B. 1994. Variations in abundance and distribution of demersal fish species in the coastal zone of the Southeastern North Sea between 1980 and 1993. *Demersal Fish Committee*, 10: 1-19.

Lima, C. 1986. Impacto da poluição por mercúrio nos organismos aquáticos da Ria de Aveiro. *Relat. Inst. Nac. Invest. Pescas*, 66: 1-28.

Loneragan, N.R. & Potter I.C. 1990. Factors influencing community structure and distribution of different life-cycle categories of fishes in shallow waters in a large Australian estuary. *Mar. Biol.,* 106: 25-37.

Lucas, M.F.; Caldeira, M.T.; Hall, A.; Duarte, A.C. & Lima, C. 1986. Distribution of mercury in the sediments and fishes of the lagoon of Aveiro, Portugal. *Water Sci. Technol.*, 18: 141-148.

Ludwig, J.A. & Reynolds, J.F. 1988. *Statistical Ecology. A primer on methods and computing*. Wiley-Interscience Publications, New York, Chichester, Brisbane, Toronto, Syngapore.

Marshall, S. & Elliott, M. 1996. The structure of the fish assemblage in the Humber Estuary, U.K. *Publ. Espec. Inst. Esp. Oceanogr.,* 21: 231-242.

Marshall, S. & Elliott, M. 1998. Environmental influences on the fish assemblage of the Humber Estuary, UK. *Estuar. Coast. Shelf Sci.*, 46: 175-184.

Matthews, W.J. 1998. Diel differences in gillnet and seine catches of fish in winter in a cove of Lake Texoma, Oklahoma – Texas. *Texas J. Sci.,* 38: 153-158.

Nobre, A.; Afreixo, J. & Macedo, J. 1915. *A Ria de Aveiro, Relatório oficial do regulamento da Ria de 28 de Dezembro de 1912*. Imprensa Nacional, Lisboa.

Osório, B. 1912. Pescas e peixes. Uma nota relativa à pesca e aos peixes da Ria de Aveiro. *Bol. Soc. Geogr. Lisboa*, 30 (4-5): 216-224.

Pombo, L. & Rebelo, J.E. 2000. Ria de Aveiro ictiofauna: diversity in space and time. *Rev. Biol. (Lisboa)*, 18: 69-81.

Pombo, L. & Rebelo, J.E. 2002. Spatial and temporal organisation of a coastal lagoon fish community, Ria de Aveiro, Portugal. *Cybium*, 26 (3): 185-196.

Pombo, L.; Borges, R.; Rebelo, J.E.; Duarte, A.C. & Bóia, C. 2000. Níveis de mercúrio no músculo de peixes (especialmente robalo, *Dicentrarchus labrax*, LINNAEUS, 1758) capturados no meio natural e em pisciculturas da Ria de Aveiro. Estudos de Biogeoquímica na Zona Costeira Ibérica. In*: IX Seminário Ibérico de Química Marinha,* Aveiro: 251-259.

Pombo, L.; Elliott, M. & Rebelo, J.E. 2002. Changes in the fish fauna of the Ria de Aveiro estuarine lagoon (Portugal) during the twentieth century. *J. Fish Biol.*, 61 (Supplement A): 167-181.

Rakocinski, C.F.; Lyczkowski-Shultz, J. & Richardson, S.L. 1996. Ichthyoplankton assemblage structure in Mississippi Sound as revealed by canonical correspondence analysis. *Estuar. Coast. Shelf Sci.*, 43: 237-257.

Rebelo, J.E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries*, 15 (3): 403-415.

Rogers, S.G.; Targett, T.E. & van Sant, S.B. 1984. Fish nursery use in Georgia salt-marsh estuaries: the influence of springtime freshwater conditions. *Trans. Am. Fish. Soc.*, 113: 595-606.

Shannon, C.E. & Weaver, W. 1949. *The mathematical theory of communication.* University of Illinois Press, Urbana.

Sokal, R.R. & Rohlf, J.F. 1995. *Biometry.* 3rd ed. W.H.Freeman and company, New York.

Ter Braak, C.J.F. 1988. *Canoco-a Fortran program for Canonical Community Ordination.* Microcomputer Power. Ithaca, New York.

Thiel, R.; Sepulveda, A.; Kageman, R. & Nellen, W. 1995. Environmental factors as forces structuring the fish community of the Elbe estuary. *J. Fish Biol.*, 46: 47-69.

Thorman, S. 1986. Seasonal colonization and effects of salinity and temperature on species richness and abundance of fish of some brackish and estuarine shallow waters in Sweden. *Holarctic Ecology*, 9: 126-132.

Van Leeuwen, P.I.; Rijnsdorp, A.D. & Vingerhoed, B. 1994. Variations in abundance and distribution of demersal fish species in the coastal zone of the Southeastern North Sea between 1980 and 1993. *Demersal Fish Committee*, 10: 1-19.

Whitehead, P.J.P.; Bauchot, M.-L.; Hureau, J.-C.; Nielsen, J. & Tortonese, E. 1986. *Fishes of the North-eastern Atlantic and the Mediterranean*. 3 vols. UNESCO, U.K.

Whitfield, A.K. 1996. Fishes and the environmental status of South African estuaries. *Fish. Manage. Ecol.*, 3: 45-57.

Zar, J.H. 1984. *Biostatistical Analysis*. 2nd ed. Prentice-Hall, Inc., New Jersey.

Changes in the Fish Fauna of the Ria de Aveiro Estuarine Lagoon (Portugal) during the 20th Century

Pombo, L.; Elliott, M. & Rebelo, J.E. 2002.

Journal of Fish Biology, 61 (Supplement A): 167-181

Changes in the Fish Fauna of the Ria de Aveiro Estuarine Lagoon (Portugal) during the 20th Century

Abstract

The fish biodiversity of the Ria de Aveiro has been analysed during the 20th century, as an indicator of the biological integrity of the ecosystem. 92 distinct species and 38 families of Agnatha, Chondrichthyes and Osteichthyes occurred during the period. The family and species richness showed two levels of magnitude, from the 1910s, with high values (26-28 families and 51-52 species), and during the last two decades comprising both high and low families richness (20-27 families and 41-55 species). A total of 13 species (4 non-sporadic species) have recently disappeared, belonging to Ammodytidae, Blennidae, Cyprinidae, Gadidae, Gasterosteidae, Labridae, Rajidae, Sciaenidae, Sparidae, Torpedinidae, and Triakidae families. The lagoon system has been affected by large-scale anthropogenic influences mainly the substantial development of industries and the increasing population in the watershed, in addition to overfishing, climatic changes and the recent dredging. In general, as shown by an analysis of the ecotrophic guilds present (covering functional aspects for the ecological, vertical distribution, substratum preference, feeding and reproductive guilds), the area maintained a similar structure during the whole period. No significant differences in time were recorded for any of the designated guilds. The species, grouped according to guilds, which occurred in six or seven surveys, were categorized as *frequent* whereas those recorded only once were categorized as *sporadic*. The twenty-two frequent species were mainly estuarine resident species or marine adventitious species, living in the substratum (benthic fish), on soft substratum and/or vegetation bottom, feeding strictly on invertebrates or on invertebrates and fish, or producing pelagic or benthic eggs. The nineteen sporadically-recorded species were mostly marine adventitious, demersal fishes, living above rough bottom and/or vegetation, feeding strictly on invertebrates, or producing benthic eggs or deposited into vegetation. It is concluded that the Ria de Aveiro estuarine coastal lagoon has supported similar fish communities during the past century and that these comprise representatives of various ecological types. In addition to this, the

paper further indicates the value of using a guild approach to compare areas spatially and temporally.

Keywords: Ria de Aveiro, fish assemblage, diversity, estuarine lagoon.

Introduction

Assemblages of estuarine organisms vary in time and space, largely because estuaries have widely varying environmental characteristics and they serve as nurseries for many productive and dependent marine species (Rogers *et al*., 1984 in Rakocinski *et al*., 1996; Elliott & Hemingway, 2002). The habitats, and consequently the fish assemblages, are also potentially affected by several anthropogenic influences which may have a direct influence on the food resources, distribution, abundance, growth, survival and behaviour of the fish present (Whitfield, 1996). Therefore, the links between the fish fauna and environmental variation in estuaries suggests that this taxonomic group is relevant as a sensitive indicator of biological integrity and the relative health of an aquatic ecosystem (Karr, 1981).

The importance of estuaries for fish has resulted in environmental quality objectives (EQO) being adopted to protect estuarine usage by fish and the health of fish populations (Elliott *et al*., 1988). These fish-orientated EQO include: (i) the water quality always allows the passage of migratory fish; (ii) the estuary's residential fish community is consistent with the hydro physical conditions; (iii) the benthos and sediments are of sufficient quality to support the fish populations, and (iv) the levels of persistent toxic and tainting substances in the biota should be insignificant and should not affect predatory fish.

Whitfield (1996) suggests that biological monitoring is preferable to chemical monitoring because the latter misses many of the anthropogenic-induced perturbations of aquatic systems; he concludes that the bio-monitoring options facilitate an increase in ecologically focused management of estuaries.

The Ria de Aveiro, on the west coast of Portugal is a typical estuarine coastal lagoon. The particular abiotic attributes of this system - shallowness, high turbidity, nature of the substrate, temperature, salinity and oxygen – together with its high

biotic productivity, offer excellent conditions for colonisation by many species of fish, especially teleosts (Potter *et al*., 1990; Rebelo, 1992; Pombo & Rebelo, 2000). The area is economically important because of its fisheries, industry, agriculture, sea farming, tourism and, more recently, aquaculture. With a good communication with the sea, a seasonal fish recruitment is guaranteed and the lagoon has considerable fish exploitation (commercial and recreational). The substantial relatively recent urban and industrial development in the catchment, with only minor effluent treatment, coupled with the intense port activities, both for fishing and commerce, are the main sources of pollution to the lagoon. Since 1912, ichthyological information has been obtained for the Ria de Aveiro (Osório, 1912; Nobre *et al*., 1915; Arruda *et al*., 1988; Rebelo, 1992; Pombo & Rebelo, 2000) thus contributing to the knowledge of the dynamics the fish assemblage inside the estuarine lagoon and its relationship with the adjacent ocean.

This paper presents and analyses a long-time variation of fish diversity as an indicator of the state of health and the biological integrity in a typical estuarine coastal lagoon.

Material and Methods

Study Area

The morphology of the Ria de Aveiro (Fig. 1) shows relatively recent development and although this started in the tenth century; the connection with the sea (470 m width) was first stabilized by man in 1808. The Ria de Aveiro is influenced by a maritime, temperate climate which has a well-defined seasonal variation in the air temperature and rainfall. The topography and physical characteristics were described by Barrosa (1980). The area is 42 km^2 at low tide and 47 km^2 at high tide. The depth at low tide is only 1 m over most of the lagoon, but can reach 10 m near the mouth and in the navigation channels. Tidal action mixes freshwater with seawater entering from the mouth. The tidal input is approximately between 25 and $90x10^6$ m^3 for tidal amplitudes of 1 and 3 m respectively. Currents produced by this tidal action are significant only at the mouth, the central part of the main channels and a few other restricted areas.

There is a delay of 6 hours in the times of high and low water between the mouth and the extreme margins of the lagoon.

The nature of the sediments, in particular the granulometry, is extremely variable. Its composition varies between 20 to 90% sand, 10 to 80% of silt and 0 to 30% of clay. In the north the sediments are finer but become coarser with progression to the south (Borrego *et al*., 1994).

The lagoon receives considerable raw and treated wastewater effluent and three main pollution types are apparent: organic and chemical pollution from paper-pulp factories (in the rivers of Vouga and Antuã); chemical pollution, particularly mercury, from the industrial area of Estarreja (in Laranjo area); and microbial contaminants from the urban sewage effluent and cattle raising areas (Ílhavo channel, Vouga river and Ovar channel) (Hall, 1980; Lima, 1986; Lucas *et al*., 1986; Borrego *et al*., 1994).

Fish Sampling

General

This study collates data from several ichthyological surveys in the Ria de Aveiro during the past century: Osório (1912), Nobre *et al.* (1915), Arruda *et al*. (1988), Rebelo (1992), Pombo & Rebelo (2000) in addition to including two years (1998/99 and 1999/00) of recent, previously unpublished data (Table 1).

Table 1 - Summary of analysed works. The location of sampling stations are shown in Fig. 1; nk – not known data.

Works references	Periodicity	Sampling period	Referenced date	Sampling stations
Osório (1912)	nk	nk	1912	nk
Nobre *et al.* (1915)	nk	nk	1915	nk
Arruda *et al.* (1988)	bimonthly	1980/81	1981	B, C, G, L, M, O, R, S, T, V
Rebelo (1992)	monthly	1987/88	1988	A, B, C, G, L, O, R, S, T, V
Pombo & Rebelo (2000)	monthly	1996/97	1997	A, B, C, G, L, R, S, T, V
Present work	monthly	1998/99	1999	A, B, C, G, L, R, S, T, V
Present work	monthly	1999/00	2000	A, B, C, G, L, R, S, T, V

Osório (1912) and Nobre *et al*. (1915) did not detail the sampling methodology nor the gear used. They do not give data for biomass, density of fish fauna, abiotic parameters or sampling period. Thus, it is assumed that the publication date was the sampling period. Those first two years only gave the ranking of fish species found whereas the other papers stated the "chincha", a typical local beach seine net, as gear, and the last year of sampling is used here as the reference date (Table 1).

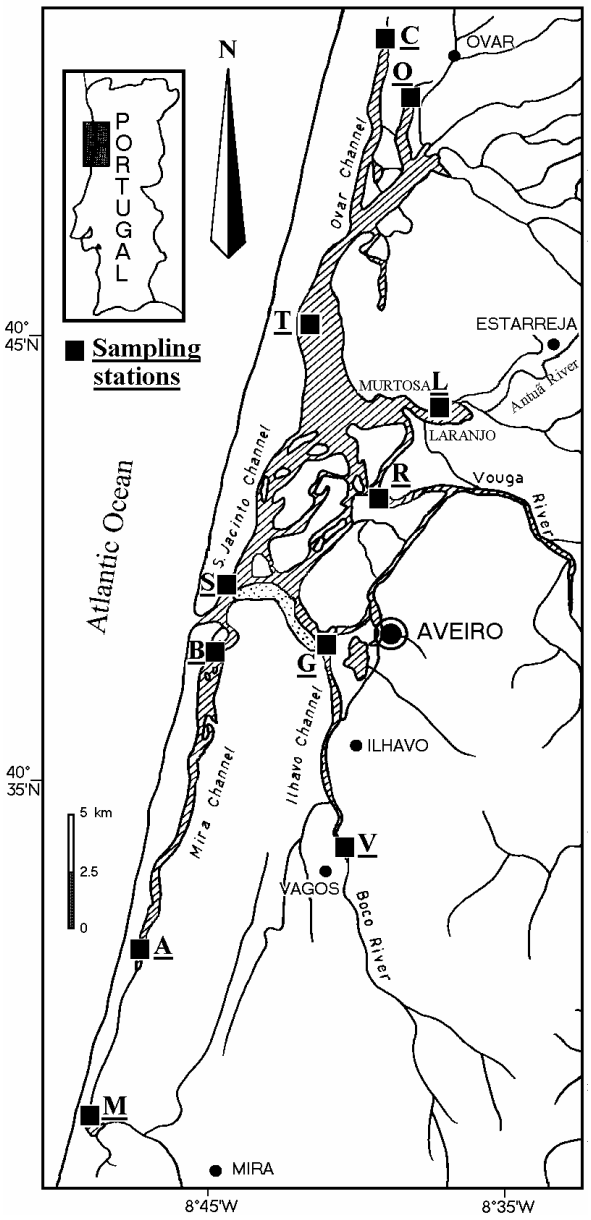

Fig.1 - Map of the Ria de Aveiro lagoon, showing the sampling stations.

Since 1988, fish have been collected monthly or bimonthly, at nine or ten selected stations (Table 1 and Fig. 1): near the mouth of the lagoon (marked B, G and S on figure 1); at the edges of the main channels (C, O, in the north, and V, A and M in the south); in the main freshwater area which is highly organically enriched (R); in the area showing the highest levels of industrial pollution (L), and approximately in the middle of the longest channel (T). The stations sampled by each work are given in the Table 1.

Present work

In the present work, the "chincha" gear used was almost rectangular in shape and composed by a central bag (a 'cod-end', 295 cm of length and 145 cm of wide), two lateral wings (12 m of length each, the wide is decreasing along the net, reaching 50 cm at the edge), two ropes (6.1 m each), and floating buoys at the top and ceramic

weights at the bottom of the net. Stretched mesh sizes in the gear were 19 mm at the wings, 17 mm at the cod mouth, 16 mm at the cod sleeve, and 10 mm at the cod-end piece. The end of the net was fixed to the margin and the remainder was trawled in a semi-circle thus retaining within the cod-end all the fish from the area.

Samples were taken monthly at low tide in triplicate, at adjacent, non-overlapping areas. The total area enclosed by the gear was approximately 193 m^2 in each trawl.

Fishes were preserved by freezing and in the laboratory each specimen was identified, using the taxonomic keys of Whitehead et al. (1986) and Bauchot & Pras (1987).

Data Analysis

The absence of abundance and biomass data in the first two sampling years prevents a temporal comparison of the fish fauna according to those parameters. Hence only the species occurrence data have been analysed here. Accordingly, a binary matrix (of presence/absence) of species and families were created by date (Table 2) from which were produced the correspondent species and family richness figures.

In order to interrogate further the fish community characteristics, the species were grouped into five ecotrophic guilds, proposed by Elliott & Dewailly (1995):

i) **Ecological guilds -** estuarine resident species (ER), marine juvenile migrant species (MJ), marine seasonal migrant species (MS), marine adventitious visitors (MA), diadromous (catadromous or anadromous) (CA) migrant species, and freshwater adventitious species (FW);

ii) **Vertical distribution guilds** - pelagic (P), demersal (D), and benthic (B);

iii) **Substratum guilds -** sandy bottom (S), soft bottom (F), rough bottom (R), mixed bottom (M), and vegetation bottom (V). The latter is currently added to the other type of categories (SV, FV, RV or MV);

iv) **Feeding guilds** - plankton (P), invertebrates (I), other fish (F), plants (V), and detritus (D), or combination among these categories (IF). Fish can also be categorised as carnivorous (CS), partly herbivorous, partly carnivorous (HC) or omnivorous (OV);

v) **Reproductive guilds** – viviparous (V), ovoviviparous (W), and oviparous (O). The latter category can be subdivided into species producing i) pelagic eggs (Op), benthic/bottom eggs (Ob), eggs guarded by one or both parents (Og), eggs shed/protected in a nest or case or pouch (Os), and eggs deposited in/stuck to vegetation (Ov). Given a degree of confusion over the first two terms in zoological texts, the term viviparous has been used here only for that species (*Mustelus mustelus*) in which the female provides some nourishment to the young while in the brood pouch. (Maddalena *et al*. (2001) indicate that the female has a 'yolk-sac placenta'.) The term ovoviviparous is used here for those species, which have an internal brood pouch, even that created by a dual fold of skin as in the Syngnathids (pipefishes and seahorses), and which bear live young. The guild Os is used for those species, such as *Raja asterias*, which produce an external pouch containing fertilised eggs. This distinction has been revised from that given in Elliott & Dewailly (1995).

Species were classified as *frequent*, if they occurred in six or seven surveys, and as *sporadic* if they were recorded only once. The use and importance of the ecosystem for the fish was determined by assessing the preponderance of frequent and sporadic species in the different ecotrophic guilds (Fig. 4).

The relative presence of each ecotrophic category through time was determined and then the similarity between each sampling period was computed using the Bray-Curtis similarity coefficient followed by production of a dendrogram (Figs. 5, 6 and 7). The package MVSP (Kovac, 1998) was used for these analyses.

Multiple paired t-tests were used to determine if whether any year was different to any other year according to each group of guilds present and also according to all guilds combined. (Zar, 1984; Sokal & Rohlf, 1995). The package Sigma-stat for windows version 2.03 was used for these analyses.

Results

Family and Species Richness

From 1912 to 2000, 92 fish species were found in the Ria de Aveiro, comprising 38 families of Cyclostomes, Selachii and Teleostei (Table 2). The

family richness varied from 20 families, in 1997, to 28 families, in 1912 (Fig. 2) and showed two levels of family richness (Fig. 3). The first, 1912 and 1915, had high values (26-28 families) with 75 % of similarity, and the second, in the recent period, from 1981 to 2000, comprised both high and low family richness. In 1981 and 1988, with high family richness (27) formed a cluster with 80% of similarity, and 1997, 1999 and 2000, with low family richness (20-22) clustered with 60% of similarity.

Table 2 - Fish species, grouped by families, occurred in the Ria de Aveiro in time.

Family	Species	1912	1915	1981	1988	1997	1999	2000
AMMODYTIDAE	*Ammodytes tobianus*	x	x	x	x		x	
AMMODYTIDAE	*Gymnammodytes cicerelus*		x					
AMMODYTIDAE	*Hyperoplus lanceolatus*	x		x	x		x	
ANGUILLIDAE	*Anguilla anguilla*	x	x	x	x	x	x	x
ATHERINIDAE	*Atherina boyeri*				x	x	x	x
ATHERINIDAE	*Atherina presbyter*	x	x	x	x	x	x	x
BALISTIDAE	*Balistes carolinensis*						x	
BELONIDAE	*Belone belone*	x	x	x	x	x		
BLENNIDAE	*Lipophrys pholis*	x	x					
BLENNIIDAE	*Parablennius gattorugine*	x	x	x	x		x	x
BLENNIIDAE	*Parablennius sanguinolentus*	x			x		x	
CALLIONYMIDAE	*Callionymus lyra*		x	x	x	x	x	x
CARANGIDAE	*Trachurus trachurus*	x		x		x	x	x
CENTRARCHIDAE	*Micropterus salmoides*			x				
CLUPEIDAE	*Alosa alosa*	x	x			x	x	x
CLUPEIDAE	*Alosa fallax*	x	x	x	x	x	x	x
CLUPEIDAE	*Sardina pilchardus*	x	x	x	x	x	x	x
CLUPEIDAE	*Sprattus sprattus*	x	x	x				
COBITIDAE	*Cobitis taenia*			x	x			
CONGRIDAE	*Conger conger*	x	x	x			x	
COTTIDAE	*Taurulus bubalis*	x			x			
CYPRINIDAE	*Barbus bocagei*		x	x				
CYPRINIDAE	*Carassius auratus*	x						
CYPRINIDAE	*Carassius carassius*	x	x	x	x	x		x
CYPRINIDAE	*Rutilus macrolepidotus*	x	x	x				
ENGRAULIDAE	*Engraulis encrasicholus*		x	x	x	x	x	x
GADIDAE	*Ciliata mustela*	x	x	x	x		x	x
GADIDAE	*Gaidropsarus mediterraneus*	x	x		x			
GADIDAE	*Gaidropsarus vulgaris*	x	x					
GADIDAE	*Pollachius pollachius*		x					
GADIDAE	*Trisopterus luscus*	x	x				x	
GASTEROSTEIDAE	*Gasterosteus aculeatus*	x	x	x	x			x
GASTEROSTEIDAE	*Spinachia spinachia*		x					
GOBIIDAE	*Aphia minuta*			x	x	x	x	x
GOBIIDAE	*Deltentosteus quadrimaculatus*				x		x	
GOBIIDAE	*Gobius ater*				x		x	x
GOBIIDAE	*Gobius niger*	x	x	x	x	x	x	x
GOBIIDAE	*Gobius paganellus*	x	x	x	x		x	
GOBIIDAE	*Gobius strictus*				x			
GOBIIDAE	*Pomatoschistus marmoratus*						x	
GOBIIDAE	*Pomatoschistus microps*			x		x	x	x
GOBIIDAE	*Pomatoschistus minutus*	x	x	x	x	x	x	x
GOBIIDAE	*Pomatoschistus pictus*			x				
LABRIDAE	*Coris julis*		x					
LABRIDAE	*Labrus bergylta*		x				x	
LABRIDAE	*Labrus merula*						x	
LABRIDAE	*Labrus viridis*							
LABRIDAE	*Symphodus bailloni*	x	x	x	x	x	x	x
LABRIDAE	*Symphodus cinereus*						x	x
LABRIDAE	*Symphodus melops*				x	x		x
MORONIDAE	*Dicentrarchus labrax*	x	x	x	x	x	x	x
MORONIDAE	*Dicentrarchus punctatus*					x	x	
MUGILIDAE	*Chelon labrosus*	x	x	x	x	x	x	x
MUGILIDAE	*Liza aurata*	x	x	x	x	x	x	x
MUGILIDAE	*Liza ramada*	x	x	x	x	x	x	x
MUGILIDAE	*Liza saliens*				x	x	x	x
MUGILIDAE	*Mugil cephalus*	x	x	x	x	x	x	x
MUGILIDAE	*Oedalechilus labeo*				x	x		
MULLIDAE	*Mullus surmuletus*	x		x		x	x	x
PETROMYZONTIDAE	*Petromyzon marinus*	x	x		x			
PLEURONECTIDAE	*Platichthys flesus*	x	x	x	x	x	x	x
PLEURONECTIDAE	*Pleuronectes platessa*						x	
POECILIDAE	*Gambusia affinis*			x	x			x
POMATOMIDAE	*Caranx crysos*					x		
RAJIDAE	*Raja asterias*	x	x					
SCIAENIDAE	*Sciaena umbra*	x						
SCOMBRIDAE	*Scomber scombrus*	x	x				x	
SCOPHTHALMIDAE	*Scophthalmus maximus*			x			x	
SCOPHTHALMIDAE	*Scophthalmus rhombus*	x		x	x	x		x
SOLEIDAE	*Solea lascaris*			x	x	x	x	x
SOLEIDAE	*Pegusa lascaris*			x	x	x	x	
SOLEIDAE	*Solea solea*			x	x	x	x	
SPARIDAE	*Boops boops*	x	x				x	
SPARIDAE	*Diplodus annularis*				x	x	x	
SPARIDAE	*Diplodus sargus*	x	x		x	x	x	x
SPARIDAE	*Diplodus vulgaris*			x	x	x	x	
SPARIDAE	*Pagellus acarne*	x						
SPARIDAE	*Pagellus bogaraveo*	x			x			
SPARIDAE	*Sarpa salpa*		x					
SPARIDAE	*Sparus aurata*	x	x	x	x	x		x
SPARIDAE	*Spondyliosoma cantharus*	x		x	x	x	x	
SYNGNATHIDAE	*Entelurus aequoraeus*			x				x
SYNGNATHIDAE	*Hippocampus hippocampus*	x	x		x			
SYNGNATHIDAE	*Nerophis ophidion*						x	
SYNGNATHIDAE	*Syngnathus abaster*		x	x	x	x		
SYNGNATHIDAE	*Syngnathus acus*	x	x	x	x	x	x	x
SYNGNATHIDAE	*Syngnathus typhle*	x	x	x	x	x	x	x
TETRAODONTIDAE	*Lagocephalus lagocephalus*		x		x			
TORPEDINIDAE	*Torpedo marmorata*	x						
TRACHINIDAE	*Echiichthys vipera*	x	x	x	x	x		
TRIAKIDAE	*Mustelus mustelus*	x	x					
TRIGLIDAE	*Chelidonichthys lucerna*	x	x	x	x	x	x	x

The species richness varied from 41 species, in 2000, to 55 species, in 1988 (Fig. 2) and again showed two levels of magnitude (Fig. 3). The first, 1912 and 1915, had a uniformly high level of 51-52 species (64% of similarity), and the second, in the recent years, from 1981 to 2000. This latter cluster grouped the lowest number of species (41, in 2000, and 42, in 1997) with 64% of similarity,

grouped 1981 (49 species) with 1988 (55 species) with 60% of similarity, and finally grouped 1999 (53 species) with 50% of similarity.

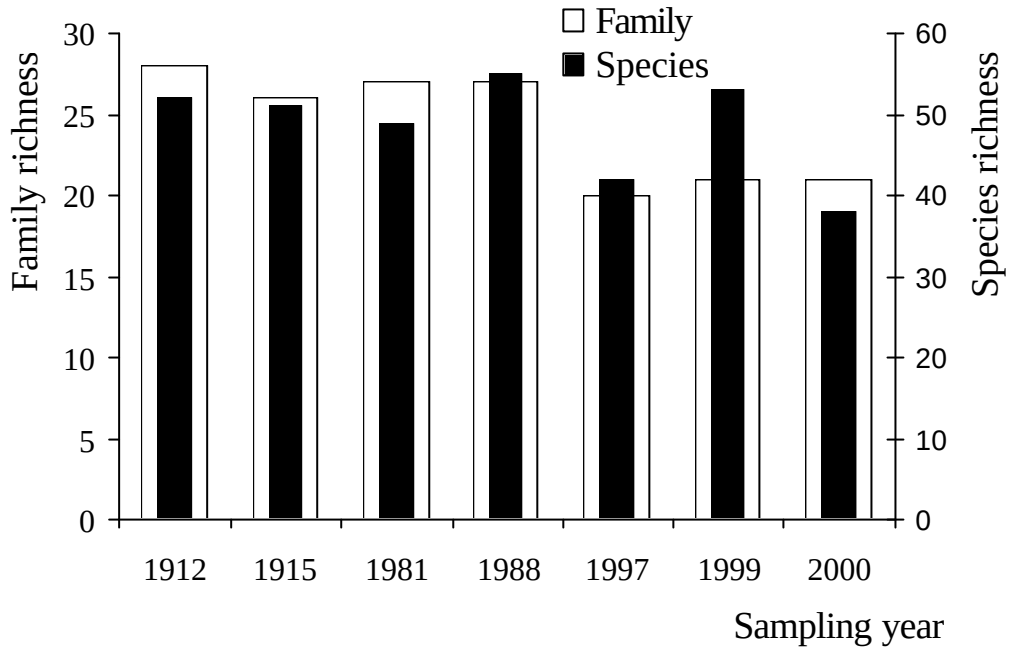

Fig. 2 - Family and species richness in time.

In 1999, despite having a low family richness, constitute one of the richest years in terms of species. Both family and species richness showed a strong level of similarity among the years (40% for species and 60 % for families) (Fig. 3).

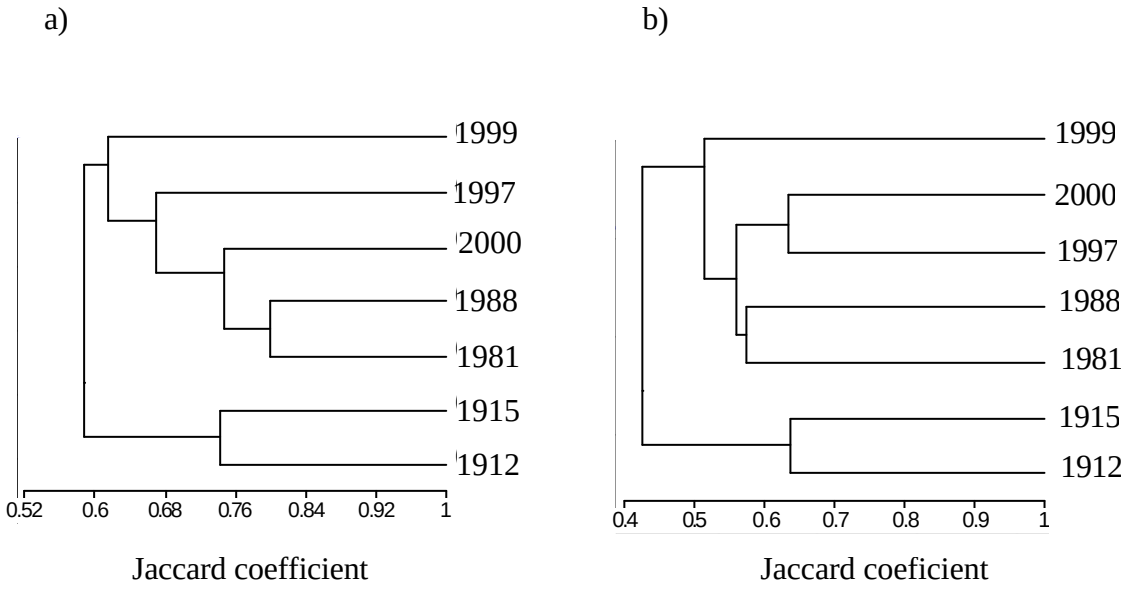

Fig. 3 - Dendrogram for (a) family binary data and (b) species binary data in time, based on Jaccard coefficient.

Proportion of Frequent and Sporadic Species

The twenty-two frequently recorded species were mainly estuarine resident species or those benthic fishes living on the soft substratum and/or vegetation bottom, feeding strictly on invertebrates or on invertebrates and fish, or producing pelagic or benthic eggs (Fig. 4).

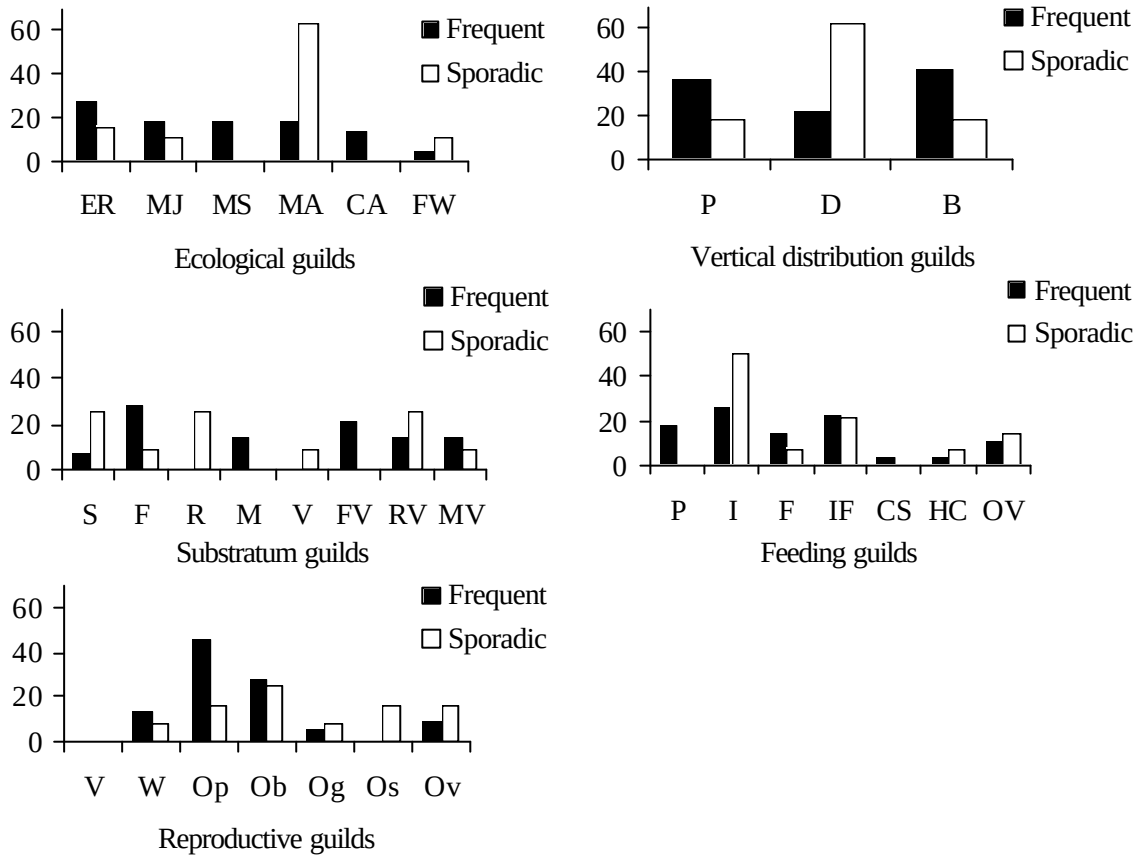

Fig. 4 - The relative occurrence of frequent and sporadic species in the different ecotrophic guilds. See text for explanation of abbreviations.

The nineteen sporadically recorded species were mostly marine adventitious demersal fishes, living above rough bottom and/or vegetation, feeding strictly on invertebrates, or producing benthic eggs or deposited into vegetation (Fig. 4).

Structure of the Fish Community based on Guilds

In general, the ecotrophic guilds maintain, in time, a similar degree of species richness. According to each group of guilds, each year was not statistically

significant different to any other year and also according to all guilds combined (p>0.5 in all cases).

Ecological Guilds

The relative proportions of each guild showed only minor variation with time (Fig. 5a). Despite this, which was confirmed by the 84 to 95 % taxonomic similarity (Fig. 5a), three main clusters are apparent. The first, and most similar (89 %), corresponded to recent surveys (1988, 1997 and 2000).

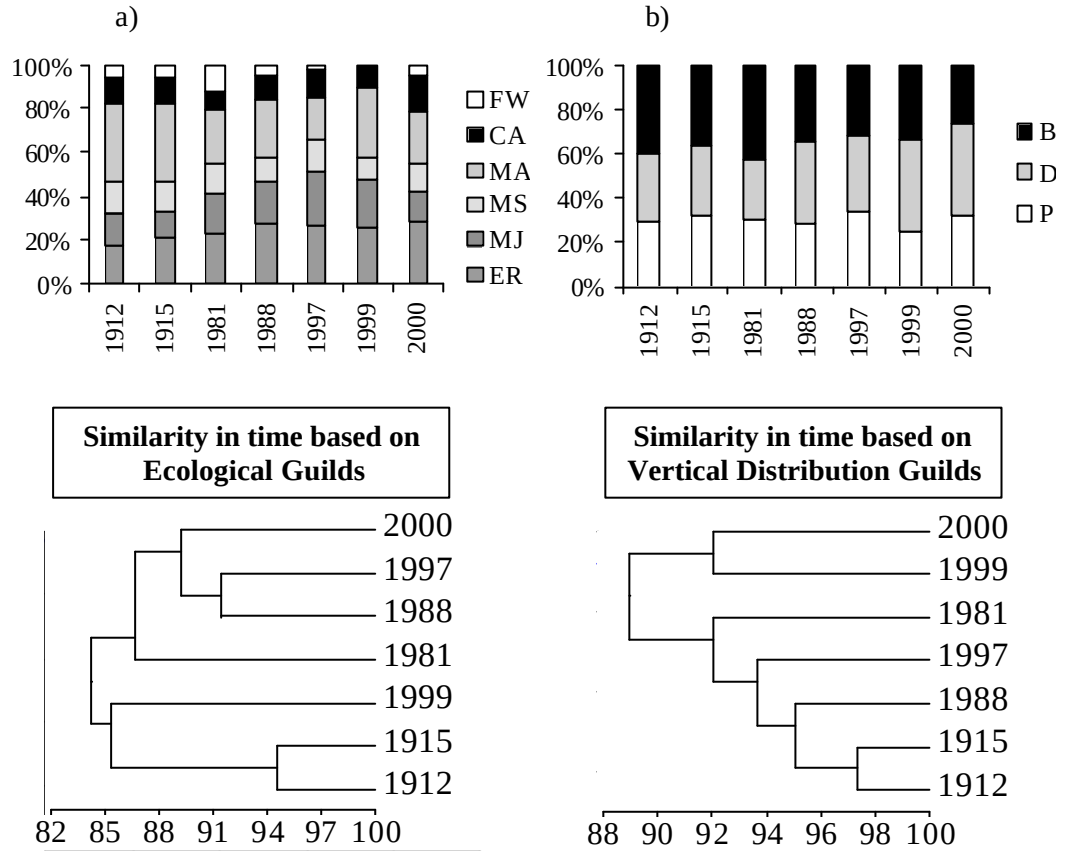

Fig. 5 - The relative presence of ecological (a) and vertical distribution (b) guilds per year. Top: percentage block diagram; bottom: similarity dendrogram. See text for explanation of abbreviations.

There was a very definite contrast between the most abundant guild, the estuarine resident species (ER), and the least abundant guild, the freshwater species (FW). The second cluster (only 1981) differs from the others especially by the relative importance of freshwater species (almost 10 %), which does not occur in the other years. However, this was the only year to include the most upstream station (station M), which had a high freshwater influence and typical freshwater

salinities. The third cluster, formed by the earliest two years and 1999 showed a higher proportion of marine adventitious species while the other guilds had similar proportions. The dredging in the Ria de Aveiro in 1997/98, which extracted 550 000 m^3 of sediment in Ovar channel, 300 000 m^3 in Murtosa channel and 660 000 m^3 in Mira channel which in turn enlarged the tidal range and the water exchange, allowed more marine adventitious species to enter the lagoon. Following the dredging, channels with a greater depth and consequently greater fish movements in the water, appeared to be environmentally more similar to the area at the beginning of the century, when typically marine species more commonly entered from the adjacent ocean.

Vertical distribution guilds

No major differences were evident in the frequency of the three guilds (Fig. 5b) although the high similarity (89% to 97%) indicates two clusters at a relatively low degree of descrimination (92% of similarity) (Fig. 5b). The earliest surveys (from 1912 and 1988) indicated a prevalence of the bottom species (B), while in the two more recent surveys demersal species (D) were dominant.

Substratum preference guilds

The species living associated with vegetation (V) or on soft bottom (F) were dominant in all the surveys (Fig. 6a). In the intermediate survey years (1981, 1988 and 1997) the species preferring soft bottom were dominant, and contributing to form a cluster with the 86 % of similarity. In the previous and the latest survey years, the species with preference for vegetation were dominant, producing a cluster with 89 % of similarity.

Feeding guilds

All the surveys showed a similar dominance of fish feeding on invertebrates and fish (IF), species feeding strictly on invertebrates (I) or carnivorous fishes (CS) (Fig. 6b). The high prevalence of IF in 1912 placed this survey in the remaining guilds with the lowest similarity (79%) (Fig. 6b). The high prevalence of I in 2000 contributed to creating a cluster with 84% similarity. The regular dominance of all

the guilds in time with only minor differences among surveys produced a high degree of similarity between 87 and 93% (Fig. 6b).

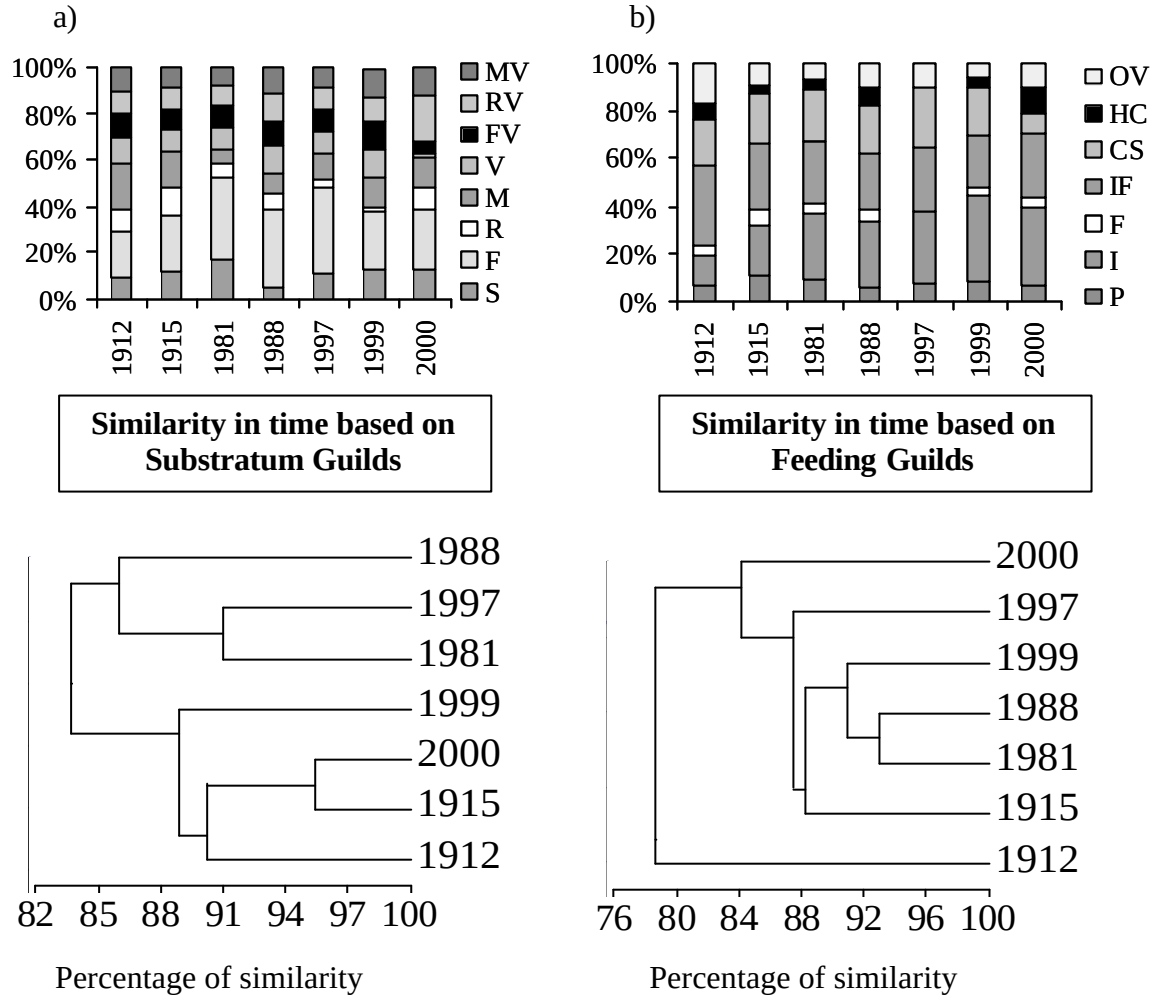

Fig. 6 - The relative presence of substratum (a) and feeding (b) guilds per year. Top: percentage block diagram; bottom: similarity dendrogram. See text for explanation of abbreviations.

Reproductive guilds

The species producing pelagic eggs (Op) or the species producing benthic/bottom deposited eggs (Ob) were dominant in all the surveys (Fig. 7). The single viviparous species (*Mustelus mustelus*) occurred only in the early surveys (1912 and 1915) contributing to group them in a cluster of 93 % of similarity. The regular dominance of all the guilds in time with minor differences among surveys produced a degree of similarity between 90 and 95% of similarity (Fig. 7).

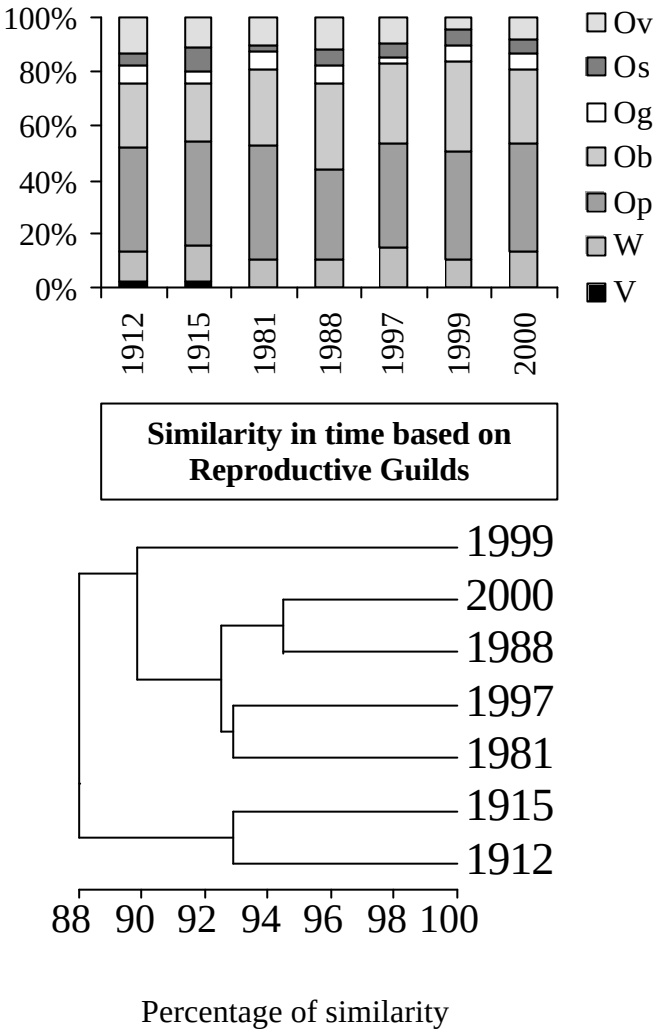

Fig. 7 - The relative presence of reproductive guilds per year. Top: percentage block diagram; bottom: similarity dendrogram. See text for explanation of abbreviations.

Discussion

Fish studies are considered important in estuarine water quality evaluation and assessments of human impacts (Elliott *et al*., 1988; Elliott & Hemingway 2002). Both fish abundance and species diversity can provide managers with a good indication of the health of a particular system (Whitfield, 1996) although there is the need to consider changes to that health over both short and long time scales. There is also the need for further studies, which attempt to understand the nature and causes of spatial and temporal changes in estuarine fish communities.

A long-time variation of species diversity is therefore valuable in providing further information on the state of ecosystem health, for example in the present study using data recorded during the past 100 years. In addition, given the increasing concern over global warming and climatic changes then such long-term assessments are important.

The fish community of the Ria de Aveiro has changed with time although that change is more apparent when considering the species identities than when analysing the community using the guild approach. This is to be expected if the view is taken that the lagoon has remained similar in its physical structure, and thus the number of niches available for colonisation but groups with particular preferences, but external and/or anthropogenic factors may have influenced the species presence. In general, two levels of magnitude of change were identified: the 1910s and the last two decades. In the first cluster, the fish were mostly marine adventitious species, benthic, preferred a soft bottom, fed on invertebrates and fish or were oviparous with pelagic eggs (Elliott & Dewailly, 1995). In recent years the number of resident species has been increasing as well as the demersal fish and the oviparous species with benthic eggs. A total of 13 species (4 non-sporadic species) have recently disappeared, belonging to Ammodytidae, Blennidae, Cyprinidae, Gadidae, Gasterosteidae, Labridae, Rajidae, Sciaenidae, Sparidae, Torpedinidae, and Triakidae families (Whitehead *et al*., 1986; Bauchot & Pras, 1987). On the other hand, 29 species (20 not sporadic species) have occurred only in the recent years belonging to Atherinidae, Balistidae, Centrarchidae, Cobitidae, Gobiidae, Labridae, Moronidae, Mugilidae, Pleuronectidae, Poecilidae, Pomatomidae, Scophthalmidae, Soleidae, Sparidae, and Syngnathidae (Whitehead *et al*., 1986; Bauchot & Pras, 1987). This may be the net result of changes (natural and anthropogenic) to the system, to its complexity and the consistency of its dynamics (Rebelo & Pombo, 2001).

The lagoonal system is well characterised although it has been affected by large-scale anthropogenic influences, mainly the substantial development of industries and the increasing population in the catchment, which can explain the non occurrence of the more pollution sensitive species and the recent occurrence of the more tolerate species (Rebelo & Pombo, 2001). In addition, overfishing

might play an important role in the disappearance of certain species, especially those with high commercial importance such as sparids, cyprinids, and especially lampreys (which was only found in the beginning of the century and in 1988).

Climatic changes, namely global warming, in general terms influence the species distribution, causing species to migrate northwards. Although the species which have disappeared may not be typically northern species, those which are intolerant of a few degrees of higher temperatures might have moved to north. The majority of species occurring only in the recent years are typically subtropical (*Balistes carolinensis*, *Pomatoschistus marmuratus*, *Labrus merula*, *Symphodus cinereus*, *Dicentrarchus punctatus*, and *Caranx crysos*) (Whitehead *et al*., 1986; Bauchot & Pras, 1987) probably moving from the south - Mediterranean, Morrocco, Azores, Madeira and Canaries.

The intense activities of the industrial and fishing port may have changed some important conditions for fish occurrence, such as the food available, niches present, and conditions for feeding, for reproduction or for shelter (refugia) against eventual predators (Pombo & Rebelo, 2000; Rebelo & Pombo, 2001) and poor hydrographic conditions. The species that prefer rocky coasts, and which sometimes have a preference for algae, such as *Lipophrys pholis*, and *Gaidropsarus vulgaris* (Whitehead *et al*., 1986; Bauchot & Pras, 1987) are amongst species that have recently disappeared in the estuary. On the other hand, recent years have shown a preponderance for mostly demersal fish, preferring brackish water and vegetation bottom.

As the depth decreased and the channels became less navigable, periodical interventions to increase the depth of the channels were made, namely the recent dredging in the Ria de Aveiro, during 1997 and 1998 as suggested in the earlier Impact Assessment (JAPA, 1993). This might explain the non-occurrence of shallow preferring species in the 1910s and, after the dredging period, the last two survey years.

During 1999, there was a high influx (12) of marine adventitious species to the estuarine lagoon, from frequent families, which enriched the number of species richness but not the number of families. The dredging in the Ria de Aveiro occurred in the previous years extracting a total of 1 510 000 m^3 of sediment from

the main channels (Ovar, Murtosa, and Mira) (JAPA, 1993). This enlarged the tidal-range and the water removal, allowing a large variety of marine adventitious species to enter the lagoon. After the dredging, channels with a greater depth and consequently a greater potential mobility of the fish in the water column, produced an environment similar to that, which occurred in the beginning of the century, when the entrance of typically marine species from the adjacent ocean was frequent.

The present analysis indicates that the frequent species are mainly estuarine resident species or marine adventitious species, living on the substratum (benthic fish) or inhabiting a soft substratum and/or vegetation bottom, feeding strictly on invertebrates or on invertebrates and fish, or producing pelagic or benthic eggs. The species that occur sporadically were mostly marine adventitious demersal fishes, living above rough bottom and/or vegetation, feeding strictly on invertebrates, or producing eggs placed on the seabed or on plants.

The analysis give differences and similarities between the years' fish assemblage but the abiotic conditions of those years are not known in sufficient details (in all the years) to allow an explanation of the differences. There is a lack of consistent and complete information of the characteristics of the years sampled (physical-chemical conditions, anthropogenic influence). When this problem is combined with the absence of information about the sampling method at the beginning of the century, it is difficult to explain fully the differences between years with respect to the fish assemblage. It is also important to point out that sampling errors and/or possible different methodology, not only in the field but also in the lab, using different taxonomic keys, probably generate such differences (Elliott & Hemingway 2002). In addition there is a lack of information from the 1930s to 1970s, although as shown here, it is possible subjectively and semi-quantitatively to compare the beginning of the 20th century to the recent years. As indicated above, recent concerns about global environmental changes, suggest that a similar study of long-term population changes is required including not only the presence of species or families (the only available data) but also the total diversity, biomass, and population dynamics, as growth, reproduction, mortality and productivity. Despite this, the available data contribute to the knowledge of the

presence or absence of each fish species along the 20th century in the Ria de Aveiro, a complex system experiencing a large variety of environmental changes.

Given the degree of changes identified in the present study, it is concluded that the Ria de Aveiro estuarine coastal lagoon appears to be somewhat resilient to anthropogenic variation. Despite the industrial, urban or fishing port pressure, it has supported very similar fish communities throughout the 20th century, comprising representatives of various ecological types. It is also concluded that fish data have a role in water quality and estuarine management (Whitfield, 1996) but further studies are required to allow the determination of changes to the integrity of an estuarine resident fish community. There is a need for continuing long-term studies to assess further both the relationship between estuarine and marine survey data and the potential value of estuary data in the management of marine fish stocks.

Acknowledgements

This study was supported financially by the *University of Aveiro* and the *Foundation for Science and Technology*. The authors are also very grateful to all the students who helped in the field and laboratory work. Three anonymous referees are thanked for their constructive comments on an earlier version of the paper.

References

Arruda, L.M.; Andrade, J.P. & Cunha, M.M. 1988. Abundance, diversity and community structure of the fish population in the Ria de Aveiro (Portugal*). Oceanol. Acta,* 11 (3): 235-240.

Barrosa, J.O. 1980. A Ria de Aveiro e a sua influência na economia da região. *Recurs.Hídric.,* 1 (3): 83-96.

Bauchot, M.L. & Pras, A. 1987. *Guía de los peces de mar de España y de Europa*. Ediciones Omega, Barcelona.

Borrego, C.; Cruz, M. & Gonçalves, P. 1994. *Estudo de avaliação da vulnerabilidade da capacidade de recepção das águas costeiras em Portugal. Relatório R 3.2. Meios receptores e suas características: (Be 1) - Ria de Aveiro, Pateira de Fermentelos e Barrinha de Mira*. IDAD. Instituto de Hidráulica e Recursos Hídricos. Universidade de Aveiro, Aveiro.

Elliott, M. & Dewailly, F. 1995. The structure and components of European estuarine fish assemblages. *Neth. J. Aquac. Ecol*., 29 (3-4): 397-417.

Elliott, M.; Griffiths, A.H. & Taylor, C.J.L. 1988. The role of fish studies in estuarine pollution assessment. *J. Fish Biol.,* 33 (Supplement A): 51-61.

Elliott, M & Hemingway, K.L. (Eds.) 2002. *Fishes in Estuaries*. Blackwell Science, Oxford.

Hall, A. 1980. Water quality problems in Ria de Aveiro. A preliminary assessment. In: Seminar on actual problems of Oceanography in Portugal, Lisboa, 20-21 Nov., 1980: 159-169.

JAPA. 1993. *Estudo de impacto ambiental – desassoreamento da Ria de Aveiro, 1ª fase*. Junta Autónoma do Porto de Aveiro. Edição do Porto de Aveiro, Aveiro.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries,* 6: 21-27.

Lima, C. 1986. Impacto da poluição por mercúrio nos organismos aquáticos da Ria de Aveiro. *Relatórios do Instituto Nacional de Investigação das Pescas,* 66: 1-28.

Lucas, M.F.; Caldeira, M.T.; Hall, A.; Duarte, A.C. & Lima, C. 1986. Distribution of mercury in the sediments and fishes of the lagoon of Aveiro, Portugal. *Water Sci. Technol.,* 18: 141-148.

Kovack. 1998. *MVSP version 3.01*. Copyright Kovack Computing Services, U.K.

Maddalena, A.; Piscitelli, L. & Malandra, R. 2001. The largest specimen of smooth-hound, *Mustelus mustelus* (Linnaeus, 1758), recorded from the Mediterranean Sea. *Biljeske - Notes*, 84: 1-8.

Nobre, A.; Afreixo, J. & Macedo, J. 1915. *A Ria de Aveiro, Relatório oficial do regulamento da Ria de 28 de Dezembro de 1912.* Imprensa Nacional, Lisboa.

Osório, B. 1912. Pescas e peixes. Uma nota relativa à pesca e aos peixes da Ria de Aveiro. *Bol. Soc. Geogr. Lisboa,* 30 (4-5): 216-224.

Pombo, L. & Rebelo, JE. 2000. Ria de Aveiro ictiofauna: diversity in space and time. *Rev. Biol*. (*Lisboa*), 18: 69-81.

Potter, I.C.; Beckley, L.E.; Whitfield, A.K. & Lenanton, R.C.J. 1990. Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and Southern Africa. *Environ. Biol. Fish.,* 28: 143-178.

Rakocinski, C.F.; Lyczkowski-Shultz, J. & Richardson, S.L. 1996. Ichthyoplankton Assemblage structure in Mississippi Sound as revealed by canonical correspondence analysis. *Estuar., Coast. Shelf Sci.,* 43: 237-257.

Rebelo, J.E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries,* 15 (3): 403-415.

Rebelo, J.E. & Pombo, L. 2001. *Os peixes da Ria de Aveiro – diversidade, ecologia e distribuição.* Câmara Municipal de Aveiro, Aveiro.

Rogers, S.G.; Targett, T.E. & van Sant, S.B. 1984. Fish nursery use in Georgia salt-marsh estuaries: the influence of springtime freshwater conditions. *Trans. Am. Fish. Soc.,* 113: 595-606.

Sokal, R.R. & Rohlf, F.J. 1995. *Biometry.* 3rd ed. W.H.Freeman and company, New York.

Whitehead, P.J.P.; Bauchot, M.-L.; Hureau, J.-C.; Nielsen, J. & Tortonese, E. 1986. *Fishes of the North-eastern Atlantic and the Mediterranean*. 3 vols. UNESCO, U.K.

Whitfield, A.K. 1996. Fishes and the environmental status of South African estuaries. *Fish. Manage. Ecol.,* 3: 45-57.

Zar, J.H. 1984. *Biostatistical Analysis*. 2nd ed. Prentice-Hall, Inc., New Jersey.

Discussion

Most ichthyofaunal studies in the Ria de Aveiro have tended to cover few abiotic factors at a time, although all scientists acknowledge that multiple variables influence both the abundance and diversity of fishes in these systems. Whitfield (1996) reviewed the factors influencing fish utilisation of South African estuaries and mentioned latitude, seasonality, catchment size, estuary size, habitat type, nearshore marine conditions, mouth depth and degree of marine influence, physical constrictions within estuarine systems, the occurrence and severity of floods, trapping of organic material by impoundments, axial salinity gradients, estuary type, timing of the open phase, the ability of species to adjust to salinity and temperature fluctuations, dissolved oxygen levels, turbidity, available food resources, predation, competition, reproductive condition, 0^+ juvenile cohort abundance, parasite loads and habitat degradation as a result of pollution or dredging.

As all of these variables cannot be controlled under field conditions, without using and experimental mesocosm approach, only some were recorded in the present study. The study aimed to achieve an overall understanding the fish diversity and assemblage structure in Ria de Aveiro and so it concentrated on the major factors but acknowledging that other factors will also be important, especially those which explain the differences in diversity, abundance or biomass in space and time.

Among the five factors studied here, temperature was found to be the best predictor of total abundance, while salinity was the most important abiotic factor affecting fish biomass. Similar patterns were observed in the Bothnian Sea (Thorman, 1986), in the Elbe estuary (Thiel *et al*., 1995), and in the Humber estuary (Marshall & Elliott, 1998). Temperature effects on the distribution of fish are enhanced by the synergistic effects of high temperature and low dissolved oxygen (Pomfret *et al*., 1991), which may result in the creation of a barrier to fish movements at temperature lower than the lethal limit. The seasonal effects and variability of migration, spawning and recruitment patterns within the area (Elliott., 1990) may well also be embedded within the temperature relationship and are likely to be the dominant factors influencing the observed distributions.

Salinity fluctuation was considered a primary factor affecting fish communities. Even the early study by Panikkar (1960) concluded that the most adaptation by fish which enter estuarine systems is an ability to adjust to changes in salinity. The magnitude of the change in salinity depends mainly upon the balance between freshwater inflow and the tidal regime, with evaporation playing a major role in lagoon systems with a high surface area. The observation of long periods of rainfall in the second year of sampling acting as a barrier to penetration by stenohaline marine species, is a possible explanation for the remarkably lower number of species in that year. Thus, apparently, the fishes of the Ria de Aveiro are therefore more tolerant of high than low salinity conditions, contrarily to the southern African estuaries (Whitfield, 1996). This is important since within the lagoon some areas are subject to periods of freshwater flooding (near the main rivers) and other subject of marine influence, whereas salinity is typically of marine environments. Furthermore, spatial differences on fish fauna are observed and only fishes tolerating these conditions (low salinities at the edges and high salinities at the mouth) are able to use the rich food resources available within this system. A few freshwater teleosts have developed hypotonic regulation and therefore excluded from estuaries (Whitfield, 1996). In the present study only two freshwater species were recorded in the lagoon.

Seasonally, there is a direct relationship between salinity and fish species richness and especially fish biomass. However, the higher catch rate in biomass during the hypersaline period (summer) could have been due to osmoregulatory stress forcing certain fish taxa entering to the area, and the high food resources may also have played a major role in increasing fish abundance and biomass (Whitfield, 1996).

High water turbidities have been shown to negatively effect fish egg survival, hatching success, feeding efficiency, growth rate and population size (Hetch & van der Lingen, 1992). Some authors suggested that the protective isolation created by turbidity, coupled with other factors, were advantageous to the survival and growth of juvenile fish (Whitfield, 1996).

It is necessary to question why turbidity is so important to juvenile fish (Blaber & Blaber, 1980). Perhaps the most obvious explanation is the cover it affords small

fishes from visual predatory teleosts and birds. Although a major requirement for the survival of small fishes in systems with high turbidity levels is an ability to evade predators, the ability to detect food in water where visibility is poor or non-existent is also important (Whitfield, 1996).

A factor frequently overlooked in the assessment of ichthyofaunal diversity is habitat variation. Estuaries with a wide range of substrata and littoral plant growing normally have higher species diversity than uniform systems (Whitfield, 1993). Wootton (1990) indicated that diversity is proportional to the diversity of habitats and also the spatial extent of the habitats. The Ria de Aveiro is comparable to other estuaries in terms of species richness (Elliott & Dewailly, 1995). Species richness depends of river floods in estuaries and on the severity of the flood, the configuration of the estuary and the extend to which food sources are affected. According to Day *et al*. (1981), certain large estuaries such as Mzimkulu, Mzimvubu and Kei (South Africa) have a relatively low ichthyofaunal diversity due to the heavy silt loads carried by rivers. The low species diversity of very turbid estuaries may therefore be linked to the indirect effect of silt deposition and substratum disturbance on aquatic macrophytes and their associated invertebrates prey, rather than turbidity *per se*.

Estuaries, in general, are characterised by a relatively low ichthyofaunal diversity but high abundance of individual taxa, most of which exhibit wide tolerance limits to the fluctuating conditions found in these systems (Whitfield, 1994). Indeed, most of estuaries are occupied by 50-100 fish species (Elliott & Hemingway, 2002), with the dominant taxa probably totalling more than a million individuals in some of the larger systems. Even small estuaries (< 1 km^2) have single species populations ranging from 10,000 – 50,000 individuals (Blaber, 1973) and fish densities in these systems invariably exceed that of the adjacent marine of freshwater environments (Whitfield, 1993).

The number of species found in an estuary also appears to be related to estuary size, with larger systems generally having a higher biodiversity (Whitfield, 1980). This is probably related to two major factors, marine interaction and habitat diversity. Small estuaries are often closed to the sea for prolonged periods, with a concomitant reduction in the number of marine species which can recruit into

these systems (Begg, 1984). Secondly, the range of habitats is generally lower in smaller systems which tend to have a greater of uniformity in both physical and biotic characteristics. Submerged aquatic macrophytes are also more diverse in large estuaries (Whitfield, 1996) when compared to small systems thus offering fish species a wider variety of habitats and foraging opportunities in the former estuarine type.

Zoogeography is also a factor that may explain differences among estuaries, where the influence of latitude can be in some cases shown. Wootton (1990) indicates that diversity decreases with increasing latitude and with decreasing depth so that shallow systems in tropical and semi-tropical areas have the highest richness. Southern African estuaries along the Atlantic coast have much lower species diversity than estuaries on the Indian Ocean coast (Whitfield, 1996). On the other hand, a complex work made by Elliott & Hemingway (2002), with collected information from throughout Europe (sampling throughout the year and covering many years and using a plethora of methods) showed that the number of species recorded for any estuary is more likely to be related to the efforts made and the methods used to study the fauna and also to the degree of pollution or habitat degradation of the individual estuarine systems. Furthermore, it was shown that habitat diversity was only one factor determining the species richness of an estuary; the complexity of the individual habitats also played an important role in determining the number of species occurring in a habitat (Elliott & Hemingway, 2002).

Seasonal changes in fish composition reflected the sequential immigration of large numbers of the juveniles of marine estuarine opportunistic species into the former area for relatively short periods. Although the ichthyofaunal composition in the Ria de Aveiro underwent the same pattern of cyclical variation in each of three almost consecutive years, the degree of intra-annual variability differed, reflecting interannual differences in the recruitment strengths of the 0^+ age classes of the different marine estuarine-opportunistics.

Catchment and estuary size are difficult to examine in isolation since both have an influence on other parameters such as hydrodynamics and mouth condition. Large estuaries in a particular region will invariably have greater fish

population than small estuaries due to increased food and habitat availability. Marais (1988) found that there was a highly significant positive correlation between estuarine fish abundance and catchment size, as well as between estuarine fish biomass and catchment area. He suggested that it was not catchment size *per se* that influenced fish stocks, but rather hydrological consequences of increased river inflow with increasing catchment size. The higher run-off from larger catchments almost invariably leads to positive estuarine salinity gradients and increased water turbidity, both of which result in increased fish abundance.

It is also important to point out that all methods and techniques of capture are selective to some degree, and unless such selectivity is taken into account, errors will arise. The selectivity may relate to species or to sex, size, and other groups within species (Pope *et al*., 1975). It is brought about by both the relative distribution of, and the interaction between, the fish and the catching gear. Variation in the response of fish to gear can arise from variation in experience, e.g., towards baited hooks (Fernö & Huse, 1983).

During the last century, the fish assemblage in the present study area remained relatively stable as shown by the persistence of species, the agreement between years in rank of common species, and the high overlap of monthly records. Although the fish assemblage in Ria de Aveiro may have changed markedly in the first years of the century that change is more apparent when considering the species identities than when analysing the community using guild approach. External and anthropogenic factors may, however, have influenced the species presence (Rebelo & Pombo, 2001).

The lagoonal system is well characterised although it has been affected by large-scale anthropogenic influences, mainly the substantial development of industries and the increasing population in the catchment, which can explain the non occurrence of the more pollution sensitive species and the recent occurrence of the more tolerate species (Rebelo & Pombo, 2001). In addition, overfishing, climatic changes, the intense activities of the industrial area and fishing port might play an important role in the disappearance of certain species, although in general terms the number of species is maintained the same, i.e., some species

disappeared over the years while others are new in the lagoon, as shown by comparisons between the previous years of the century and the most recent research (Rebelo & Pombo, 2001).

According to Connell and Sousa (1983), several criteria are necessary to assess stability (i.e. resistance and resilience) of biotic assemblages, including: 1) populations are examined over sufficiently long time periods (i.e., several population turnovers), and 2) baseline information on an equilibrium state must be adequately established. Because of extensive samples, we can make some inference on the stability of the Ria de Aveiro.

First, the fish assemblage in the present study area appeared to be resilient to most abiotic factors that occurred between sampling periods. Because there was no sampling between 1915 and 1981, it is not possible to comment on the consistency of the assemblage between this period. It is know that the 1912 fish assemblage was similar to that in 1915, by 1981 the fish assemblage was similar to that in 1988, and finally, the last three years were similar between them, suggesting that the assemblage showed little consistency along the years, despite of a lack of sampling between 1915 and 1981.

As already mentioned above several factors surely influenced the fish fauna between this century, and species introductions (or disappearance) also can be considered a disturbance by their biotic interactions between them, mainly competition (Whitfield, 1996).

In essence, as multiple factors are continually impinging on the lives of fishes in estuaries, research emphasis should move away from attempting to determine the influence of isolated environmental variables and adopt a more holistic approach. Over a wide temporal scale, the only available data relate to species presence indicating that, although the number of species was relatively constant, the nature of the taxa varied with time. Furthermore, although this work suggests a relatively stable assemblage in the recent years, considering the proximity of number of individuals recorded, the biomass and the number of species, continued monitoring over subsequent years will provide further information on responses of the assemblage to disturbance over longer temporal scales.

References

Alcolado, P.M. 1996. Controversia sobre la relación entre la diversidad de especies y la estabilidad de las comunidades. *Avicenia*, 4/5: 13-26.

Arruda, L.M.; Andrade, J.P. & Cunha, M.M. 1988. Abundance, diversity and community structure of the fish population in the Ria de Aveiro (Portugal). *Oceanologica Acta*, 11 (3): 235-240.

Begg, G.W. 1984. The comparative ecology of Natal's smaller estuaries. *Natal town and Regional Planning Report*, 62: 1-182.

Begon, M.; Harper, J.L & Townsend, C.R. 1990. *Ecology: individuals, populations and communities.* Blackwell Sci. Publ., Brookline Village.

Bevelhimer, M.S. & Adams, S.M. 1996. Assessing contaminant distribution and effects in a reservoir fishery. In: Miranda, L.E. & DeVries, D.R. (Eds.), *Multidimensional approaches to reservoir fisheries management.* American Fisheries Society Symposium 16. Bethesda, Maryland, U.S.A. 119-132 p.

Blaber, S.J.M. & Blaber, T.G. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *J. Fish Biol.*, 17: 143-162.

Blaber, S.J.M. 1973. Population size and mortality of the marine teleost *Rhabdosargus holubi* (Pisces: Sparidae) in a closed estuary. *Mar. Biol.*, 21: 219-225.

Blaber, S.J.M. 1991. Deep sea, estuarine and freshwater fishes: life history strategies and ecological boundaries. *S. Afr. J. Aquat. Sci.*, 17 (1/2): 2-11.

Blaber, S.J.M.; Brewer, D.T. & Salinin, J.P. 1989. Species composition and biomassa of fish in different habitats of a tropical northern Australian estuary: their occurrence in the adjoining sea and estuarine dependence. *Estuar. Coast. Shelf Sci.*, 29: 509-531.

Chaplin, F.S.; Lubchenco, S. & Reynolds, H.L. 1995. Biodiversity effects on patterns and processes of communities and ecosystems. In: Heywood, V.H. (Ed.), *Global diversity assessment.* UNEP. Cambridge University Press. Cambridge. 289-301 p.

Connel, J.H. & Sousa, W.P. 1983. On the evidence needed to judge ecological stability or persistence. *Am. Nat.*, 121: 789-824.

Day, J.H. & Grindley, J.R. 1981. The estuarine ecosystem and environmental constraints. In: Day, J.H. (Ed.), *Estuarine Ecology with particular reference to Southern Africa*. Balkema. 345-372 p.

Elliott, J.M. 1990. The need for long-term investigations in ecology and contribution of the Freshwater Biological Association. *Freshwat. Biol.*, 23: 1-5.

Elliott, M. & Dewailly, F. 1995. The structure and components of European estuarine fish assemblages. *Neth. J. Aquac. Ecol.*, 29 (3-4): 397-417.

Elliott, M. & Hemingway, K.L. (Eds.). 2002. *Fishes in Estuaries*. Blackwell Science, Oxford.

Elliott, M. & Taylor, C.J.L. 1989. The structure and functioning of an estuarine/marine fish community in the Forth estuary, Scotland. In*:* Proceedings of the 21st European Marine Biology Symposium Gdánsk, 14-19 Sept. 1986. unknown Eds. Polish Academy of Sciences. Institute of Oceanology. Warsaw. 227-240 p.

Elton, C.S. 1958. *The ecology of invasions by animals and plants*. Methuen, London.

Fernö, A. & Huse, I. 1983. The effect of experience on the behaviour of cod towards a baited hook. *Fish. Res*., 2 (1): 19-28.

Gido, K.B.; Matthews, W.J. & Wolfinbarger, W.C. 2000. Long-terms changes in a reservoir fish assemblage stability in an unpredictable environment. *Ecol. Appl.*, 10 (5): 1517-1529.

Hayes, D.B.; Ferreri, C.P. & Taylor, W.W. 1996. Linking fish habitat to their population dynamics. *Can. J. Fish. Aquat. Sci*., 53 (suppl. 1): 383-390.

Hecht, T. & Van Der Lingen, C.D. 1992. Turbidity-induced changes in feeding strategies of fish in estuaries. *S. Afr. J. Zool.*, 27: 95-107.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries*, 6: 21-27.

Loneragan, N.R. & Potter, I.C. 1990. Factors influencing community structure and distribution of different life-cycle categories of fishes in shallow waters in a large Australian estuary. *Mar. Biol.,* 106: 25-37.

Marais, J.F.K. 1988. Some factors that influence fish abundance in South African estuaries. *S. Afr. J. Mar. Sci.*, 6: 67-77.

Marshall, S. & Elliott, M. 1998. Environmental influences on the fish assemblage of the Humber Estuary, UK. *Estuar., Coast. Shelf Sci.*, 46:175-184.

May, R.M. 1976. Patterns in multi-species communities. In: May, R.M. (Ed.), *Theoretical ecology: principles and applications.* Blackwell Sci. Pub. Oxford, London. 142-162 p.

McKenna, J.E. Jr. 2001. Biological structure and dynamics of littoral fish assemblage in the Easterns Finger Lakes. *Aquat. Ecosyst. Health Manage.*, 4: 91-115.

Nobre, A.; Afreixo, J. & Macedo, J. 1915. *A Ria de Aveiro, Relatório oficial do regulamento da Ria de 28 de Dezembro de 1912*. Imprensa Nacional, Lisboa.

Orians, G.H. 1975. Diversity, stability and maturity in natural ecosystems. In: van Dobben, W.H. & Lowe-McConnel, R.H. (Eds.), Unifying concepts in Ecology. Junks. The Hague. 139-150 p.

Orth, D.J.; White, R.J. 1993. Stream habitat management. In: Kohler, C. & Hubert, W. (Eds.), Inland fisheries management in North America. American Fisheries Society. Bethesda. 205-230 p.

Osório, B. 1912. Pescas e peixes. Uma nota relativa à pesca e aos peixes da Ria de Aveiro. *Bol. Soc. Geogr. Lisboa*, 30 (4-5): 216-224.

Panikkar, N.K. 1960. Physiological aspects of adaptation to estuarine conditions. *Australian Fisheries Council Proceedings*, 32: 168-175.

Pecenko, Y.A. 1982. *Principios y métodos del análisis cuantitativo en las investigaciones faunísticas.* Ed. Ciencia, Madrid.

Pielou, E.C. 1975. *Ecological diversity*. Wiley Interscience.

Pombo, L. & Rebelo, J.E. 2002. Spatial and temporal organisation of a coastal lagoon fish community, Ria de Aveiro, Portugal. *Cybium*, 26 (3): 185-196.

Pombo, L.; Elliott, M. & Rebelo, J.E. 2002. Changes in the fish fauna of the Ria de Aveiro estuarine lagoon (Portugal) during the twentieth century. J. *Fish Biol.*, 61 (Supplement A): 167-181.

Pomfret, J.R.; Elliott, M.; O'Reilly, M.G. & Philips, S. 1991. Spatial and temporal patterns in the fish communities in the U.K. North Sea estuaries. In: Elliott, M. & Ducrotoy, J-P. (Eds.), *Estuaries and Coasts: Spatial and Temporal Intercomparisons.* Olsen & Olsen. Fredensborg, Denmark. 277-284 p.

Pope, J.G.; Margetts, A.R.; Hamley, J.M. & Akyuz, E.F. 1975. *Manual of Methods for Fish Stock Assessment, Part III. Selectivity of Fish gear FAO Fisheries Technical Paper 41. (Rev. 1).* FAO Fisheries Dept., Rome.

Potter, I.C.; Claridge, P.N.; Hyndes, G.A. & Clarke, K.R. 1997. Seasonal, annual and regional variations in Icthyofaunal composition in the Inner Severn Estuary and Inner Bristol Channel. *J. Mar. Biol. Ass. U.K*., 77: 507-525.

Rakocinski, C.F.; Lyczkowski-Shultz, J. & Richardson, S.L. 1996. Ichthyoplankton Assemblage structure in Mississippi Sound as revealed by canonical correspondence analysis. *Estuar. Coast. Shelf Sci.*, 43: 237-257.

Rebelo, J.E. & Pombo, L. 2001. *Os peixes da Ria de Aveiro – diversidade, ecologia e distribuição*. Câmara Municipal de Aveiro, Aveiro.

Rebelo, J.E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries*, 15 (3): 403-415.

Rogers, S.G.; Targett, T.E. & van Sant, S.B. 1984. Fish nursery use in Georgia salt-marsh estuaries: the influence of springtime freshwater conditions. *Trans. Am. Fish. Soc*., 113: 595-606.

Sala, O.E. 1994. Ecological complexity and ecosystems function: The effect of global change. *Global Change Newsletter*, 18: 1-2.

Shepard, R.B. 1984. The logseries distribution and Mountford's similarity index as a basis for the study of stream benthic community structure. *Freshwat. Biol.,* 14: 53-71.

Thiel, R.; Sepulveda, A.; Kageman, R. & Nellen, W. 1995. Environmental factors as forces structuring the fish community of the Elbe estuary. *J. Fish Biol.*, 46:47-69.

Thorman, S. 1986. Seasonal colonization and effects of salinity and temperature on species richness and abundance of fish of some brackish and estuarine shallow waters in Sweden. *Holarctic Ecology*, 9: 126-132.

Tremain, D.M. & Adams, D.H. 1995. Seasonal variations in species diversity, abundance and composition of fish communities in the Northern Indian River Lagoon, Florida. *Bull. Mar. Sci.*, 57 (1): 171-192.

Vernberg, F.J. 1982. Environmental adaptation to lagoon systems. In: Oceanol. Acta. International Symposium on coastal lagoons, 8-14 Sept. 1981, UNESCO. Bordeaux. 7-415 p.

Whitfield, A.K. & Elliott, M. 2002. Fishes as indicators of environmental and ecological changes within estuaries – a review of progress and some suggestions for the future. *J. Fish Biol.*, 61 (Suppl. A): 229-250.

Whitfield, A.K. 1980. A checklist of fish species recorded from Maputaland estuarine systems. In: Bruton, M.M. & Cooper, K.H. (Eds.), *Studies on the Ecology of Maputaland*. Grahamstown. Rhodes University. 204-209 p.

Whitfield, A.K. 1993. Fish biomass estimates from the littoral zone of an estuarine coastal lake. *Estuaries*, 16: 280-289.

Whitfield, A.K. 1994. Fish species diversity in southern African estuarine systems: an evolutionary perspective. *Environ. Biol. Fish.*, 40: 37-48.

Whitfield, A.K. 1996. A review of factors influencing fish utilization of South African Estuaries. *Trans. Roy. Soc. S. Afr.,* 51: 115-137.

Wootton, R.J. 1990. *Ecology of Teleost Fishes*. Chapman and Hall, New York.

Young, G.C.; Potter, I.C.; Hyndes, G.A. & de Lestang, S. 1997. The Ichthyofauna of an intermittently open estuary: implications of bar breaching and low salinities on faunal composition. *Estuar. Coast. Shelf Sci.*, 45: 53-68.

Zaret, T.M. 1982. The stability-diversity controversy: a test of hypothesis. *Ecology*, 63: 721-731.

CHAPTER II – Population Dynamics

Introduction

The dynamics of a fish population are the ultimate measures of the quality and quantity of its habitat, as growth, survival and reproduction are directly related to requirements for specific abiotic and biotic resources. The density-dependent response of a species depends upon its biology and the way that habitat alteration affects its vital rates (Hayes *et al.* 1996).

It has long been known that, to have a good fishery, it is necessary to have a good habitat. However, it has only been in the last two decades that a concerted effort has been made to define and quantify habitat for a fish population. The habitat requirements for a fish population are directly related to the requirements for an individual's growth and survival, i.e., the quality and quantity of its niche (Hayes *et al*., 1996). The intersection of the niche and the environment defines the utility of a habitat for a species. It is important to note that an individual organism's niche varies over time and between individuals because of their genotype but also their phenotypical differences and tolerances, and acclimation history (Shutter, 1190). As such, habitat requirements can vary for an individual over its life and can vary between individuals of the same species. If the biotic and abiotic requirements are at optimal levels, based on the genetic makeup of the population, then growth and survival of fish in the population would be maximised (Hayes *et al*., 1996).

When evaluating the habitat requirements of a fish population, it is important to identify whether these are consumable or non-consumable resources and if they are dynamically affected or not by the population itself. This categorisation determines whether the population will respond in a density-dependent or density-independent manner to habitat alterations and the time needed for population responses to occur (Hayes *et al*., 1996). The response of fish growth and survival to habitat alterations will vary between these resource categories. Independently of whether the habitat is affected or not by the population that lives on it, the population response will differ among habitat components, depending upon the degree to which they are a limiting factor. Quantifying of the shape of these populations' dynamic response functions for each of these habitat categories is essential for fisheries managers to design appropriate habitat management plans.

Additionally, such information will allow managers and policy makers to better predict the impact of habitat alterations to the production dynamics of a fish population (Hayes *et al*., 1996).

This can only be done by approaching habitat analysis from an analysis of its physical and chemical components but also using the biological components. An evaluation of one component without the other will prove of little use for fisheries managers as it is the interaction between the two components (biological and physical-chemical components) that creates the production potential for the fish population that will be focused in the third chapter.

An example of the importance of the synergism between biotic and abiotic habitat components are expressed in the first paper of this chapter by selecting ten species and showing the influence of abiotic parameters on the distribution of fish, and analysing the feeding preferences of each species predicting their biotic relationships between them and also the spatial segregation of fish in relation to feeding preferences.

It is important to understand the biotic interactions, such as feeding and predator-prey relationships, as a means of interpreting the community structure and the relationship with the habitat characteristics (Wootton, 1990; Elliott & Hemingway, 2002). Thus it is important to understand feeding interactions in relation to the rate of growth, maturation and fecundity of fishes, their resistance to the impact of unfavourable factors, migratory activity, life strategy, etc (Pavlov & Kasumyan, 1998).

Food relationships in fishes include diverse and complex biotic relations. Trophic relations are realised through feeding and feeding behaviour, predatory-prey and parasite-host relationships, etc., are a functional basis of natural communities and provide for their unit, stability, and resistance (Homer *et al*., 1981).

If there is competition between species (interspecific) and within species between life stages (intraspecific) then the fish community structure is characterised by a resource partitioning, which is how different species and different life stages make use of available resources. Differences may due to many

factors, one of them being competition for food and space (Moreno & Castro, 1995; Elliott & Hemingway, 2002).

Competition for food can be defined as any interaction between individuals that causes a reduction in foraging success to one or the other. A fish which takes mobile prey species will have a high competitive ability if it has rapid reaction times, can swim fast and has a high degree of capture success (Gill & Hart, 1996), while other species rely on camouflage, foraging on sedentary species, etc.

As with many aspects of fisheries research, few unifying concepts regarding trophic dynamics have emerged from the extensive data base that presently exists for the lagoon as fish trophic relationship data have never been analysed in the Ria de Aveiro; however, feeding preferences presented here will be a brief, general description of how trophic relationships may be coupled with fish distribution.

The approach used to analyse the food habit data was the so-called frequency of occurrence of prey items (Hyslop, 1980). Food items were identified (to the lowest possible taxonomic level), and fish were grouped as small, medium and large, when sufficient individuals are present (more than 30). Population food habits were analysed by clustering the size class dietary data. This clustering procedure brought to mind a generally overlooked aspect of fish population food habits (Marshall & Elliott, 1997).

The case of two sympatric species, *Atherina boyeri* and *A. presbyter*, was particularly studied to verify how a resident species, which spend its entire life in the lagoon, and a marine juvenile, which uses the lagoon as nursery, interact.

Length data, that are likely to be the most commonly collected information from fish samples (Pauly, 1980), were particularly used in this study. A decision had to be made between total, fork, and standard lengths. In this study total length was recorded for all the fishes. Weight data was also in form of total weight.

The description of a population's age-structure, cohort analysis, the construction of life tables, and the determination of growth rates all depend on the ability to determine the age of fish. Ageing techniques are therefore a fundamental part of ecological and fishery survey work has attracted considerable attention (Bagenal, 1978). Fish are aged on an annual basis (with January 1 birthdays) and

are described as 0-group or 0^+, 1-group or 1^+, etc. The two basic techniques used were length-frequency analysis and the counting of growth rings in skeletal structures such as otoliths and scales. Both techniques were used in these studies to validate the obtained data.

Length-frequency analysis was based on a rapid and easy data collection and was usually successful for separating at the youngest age-classes (which account for the bulk of biological production in most populations). Large samples were required, as few individuals for each age-group, missing year-classes, and overlap between groups can give rise to errors.

There are few studies on either interaction and/or competition between fish species in the lagoon, despite these being key factors for evaluating parameters such as natural recruitment and distribution. Furthermore, very few fisheries exploit single species and it is increasingly being recognised that management should be based on communities or multispecies assemblages rather than the traditional single-species approach. The latter usually ignores the biological interactions between species and the effects that the exploitation of one species unintentionally has on others.

The aim of this chapter was to research population dynamics in terms of spatial and temporal characteristics and the influence of environmental characteristics on the fish assemblage structure. The ecology, age, growth and diet of two Atherinids species (*A. boyeri* and *A. presbyter*) were studied in detail intending to be a useful contribution to the identification of those species besides the wide used traditional taxonomy.

To reach the aims of the study, ten abundant fish populations were studied in detail because the lack of information of these species in the lagoon, and the importance of the species themselves (Moreno & Castro, 1995). The consistence data of this work was established by month samplings during two subsequent years. With respect to Atherinids, the length and weight were registered, the age was determined by otholiths and scales and the stomach contents were individually analysed.

The hypotheses which intended to be answered in this chapter were to test significant differences among the total abundance and total biomass of each species between sites in each year. The same statistical test was assessed to test significant differences among the abiotic parameters between sites and between months. Furthermore, it was tested if whether each abiotic parameter of each area of one year was different to the same area of the following year and which factor was responsible for maintaining structure of fish assemblages in each year. For the study of Atherinids, the length distributions of both species were compared, and the slopes of fish length-weight and the otolith length-weight relationships were also compared. Statistical differences were tested on spatial variation and on age variation in diet breadth of two species.

The first paper was designed to improve the knowledge of whether the fish assemblage changes in a predictable way as abiotic factors change, and whether different sites differ significantly in the fish assemblage. The second paper intended to distinguish two species, *Atherina boyeri* and *Atherina presbyter*, (through their ecology, age and growth patterns, according to their occurrence in a typical estuarine coastal lagoon). And finally, the third paper compared the qualitative and quantitative dietary of both Atherinids species, with spatial and foraging behaviour patterns, and determined their diet overlap in order to analyse biotic relationships, such as competition, and mainly emphasise distinct behaviour features, as food strategy.

Environmental Influences on Fish Assemblage Distribution of an Estuarine Coastal Lagoon, Ria de Aveiro (Portugal)

Pombo, L.; Elliott, M. & Rebelo, J.E. 2005.

Scientia Marina, in press

Environmental Influences on Fish Assemblage Distribution of an Estuarine Coastal Lagoon, Ria de Aveiro (Portugal)

Fish assemblage was examined for patterns in spatial and seasonal structure within an estuarine coastal lagoon, Ria de Aveiro. Two years of abiotic conditions variation were recorded to identify factors responsible for maintaining structure of fish assemblages. Nine sites were monthly sampled with a traditional beach-seine net “chincha”, between November 1998 and October 2000. Fish abundance and biomass changed significantly between sites. Temperature was found to be the most important abiotic factor affecting the abundance (number of fish) distribution of fish assemblage, which is more related to the seasonal migrations rather than to spatial migrations. Salinity was the most important abiotic factor affecting the fish biomass, with temperature also having a major influence. The other analysed abiotic parameters also showed some influence on the distribution of fish, although, isolated from the other controlled and/or uncontrolled factors, they could not fully explain all the differences between assemblages. Feeding analysis indicates that fish assemblage is mostly dependent on small benthic and pelagic crustaceans and/or detritus, although they can feed opportunistically on other prey. The low spatial segregation of fish in relation to feeding preference indicates that, in a food-rich lagoon as Ria de Aveiro, the environmental-biological interactions appear to have a greater effect on fish distribution than do biological interactions.

Keywords: fish fauna, diversity, environmental factors, Ria de Aveiro.

Introduction

Assemblages of estuarine organisms vary in time and space, largely because estuaries have widely varying environmental characteristics and they serve as nurseries for many productive and dependent marine species (Rogers *et al*., 1984 in Rakocinski *et al*., 1996; Elliott & Hemingway, 2002). The habitats and fish assemblages are also potentially affected by several anthropogenic influences

which may have a direct influence on the food resources, distribution, abundance, growth, survival and behaviour of the fauna present (Whitfield, 1996).

The main estuarine water quality parameters, salinity, temperature, turbidity, pH and dissolved oxygen are known to affect fish distribution (Blaber & Blaber, 1980 *in* Marshall & Elliott, 1998). Sediment characteristics, substratum heterogeneity and vegetal cover also affect fish distribution through their influence on prey availability (Marchand, 1993) and/or protection from predators (Blaber & Blaber, 1980 *in* Marshall & Elliott, 1998).

The assessment of fish assemblage structure has a high value in estuarine quality assessment (Elliott *et al*., 1988; Pomfret *et al*., 1991) although causal links have to be determined between environmental parameters and fish assemblage structure and functioning. Identification of significant associations between fish species and habitat conditions is the first step towards incorporating environmental information into fish abundance (Perry *et al*., 1994). In general, the structure and functioning of fish communities within estuaries has been documented to a lesser extent than communities on the coast or in the open sea (Elliott & Taylor, 1989). The role of estuaries to commercial fish, such as spawning and nursery areas is relatively well understood (Haedrich, 1983), although further studies are required on aspects such as spatial usage and trophic interactions on fish assemblage.

The particular abiotic attributes of the Ria de Aveiro lagoon - shallowness, high turbidity, nature of the substrate, temperature, salinity and oxygen - associated with its high biotic productivity, offer excellent conditions for colonization by many species, especially teleosts (Potter *et al*., 1990; Rebelo, 1992; Pombo & Rebelo, 2002).

Concerning the availability of fish food within the lagoon, copepods are the most dominant group in the whole lagoon and decapods, isopods, mysids and amphipods are very abundant in most areas (Morgado, 1997). The density of the major dominant neritic zooplankton species was significantly correlated with salinity, while for estuarine species the density was significantly correlated with water temperature (Morgado, 1997). Other important study on peracaridan crustaceans (Cunha, 1999) recorded 69 species in the whole lagoon comprising

52% amphipods, 19% isopods, 19% mysids, 6% cumaceans, and 4% tanaids and also showed important spatial and temporal changes.

The biology and ecology of fish species in the Ria de Aveiro have been recently characterized in various studies (Rebelo, 1992; Rebelo & Pombo, 2001; Pombo & Rebelo, 2002; Pombo *et al.*, 2002a). Despite these studies, the environmental effects on abundant fish distribution in Ria de Aveiro have not been studied as in other estuaries and lagoons (Pomfret *et al*., 1991; Marchand, 1993; Jones *et al*., 1996; Pope & Willis, 1996; Marshall & Elliott, 1996, 1998; Irigoien *et al*., 1999; Duffy-Anderson & Able, 1999; Kuo *et al*., 2001).

The present study aims to assess the spatial and temporal characteristics and assemblage structure of abundant fish populations within an estuarine coastal lagoon. The consistence data of this paper is established by month samplings during two subsequent years. This study intends to improve the knowledge of whether the fish assemblage changes in a predictable way as abiotic factors change, and whether different sites differ significantly in the fish assemblage. The interactions of feeding habits of abundant fish species have also been examined.

Material and Methods

Study Area

The Ria de Aveiro (Fig. 1), on the west coast of Portugal, is a coastal estuarine lagoon with a maximum length of 45 km and maximum width of 11 km delimit a total area between 42 km² (low tide) and 47 km² (high tide) (Barrosa, 1980). The water volume is 70 million m^3, with an oceanic tidal contribution of between 25 million m^3 (neap-tides) to 90 million m^3 (higher spring tides). Four rivers (Vouga, Antuã, Caster and Boco) and uncounted streams flow between 3 $m^3.s^{-1}$ and 60 $m^3.s^{-1}$, due to the influence of seasonal precipitation and run-off patterns. The depth varies between 0.6 m and 10.0 m. The nature of the sediments, in particular the granulometry, is extremely variable. Its composition varies between 20 to 90% sand, 10 to 80% of silt and 0 to 30% of clay. In the north the sediments are finer but become coarser with progression to the south (Borrego *et al*., 1994).

The lagoon receives considerable raw and treated wastewater effluent and three main pollution types are apparent: organic and chemical pollution from

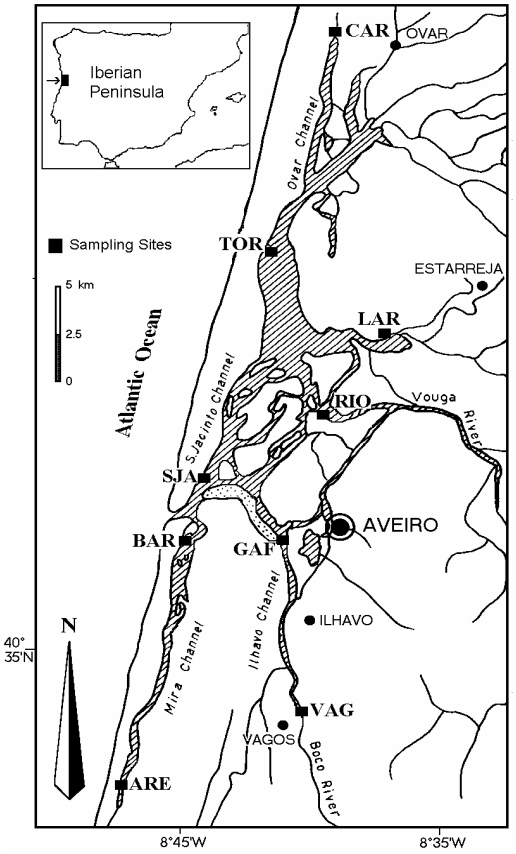

Fig. 1 - Map of the Ria de Aveiro lagoon showing sampling sites.

paper-pulp factories (in the rivers of Vouga and Antuã); chemical pollution, particularly mercury, from the industrial area of Estarreja (in Laranjo area); and microbial contaminants from the urban sewage effluent and cattle raising areas (Ílhavo channel, Vouga river and Ovar channel) (Hall, 1980; Lima, 1986; Lucas *et al*., 1986; Borrego *et al*., 1994).

Sampling Techniques

Fish were monthly sampled, between November 1998 and October 2000, with “chincha”, a traditional beach-seine net. The “chincha” gear used was almost rectangular in shape and composed by a central bag (a ‘cod-end’, 295 cm of length and 145 cm of wide), two lateral wings (12 m of length each, the width decreasing along the net, reaching 50 cm at the edge), two ropes (6.1 m each), floating buoys at the top and ceramic weights at the bottom of the net. The stretched mesh sizes in the gear were 19 mm at the wings, 17 mm at the cod mouth, 16 mm at the cod sleeve, and 10 mm at the cod-end. The end of the net was fixed to the margin and the remainder was trawled in a semi-circle thus retaining within the cod-end all the fish from the area. The net efficiency is estimated at 90% (Elliott & Hemingway, 2002).

At each site and each month, 3 non-overlapping replicate samples were taken at low spring tide, over the five days of the new moon at adjacent, non-overlapping areas: near the mouth of the lagoon (BAR, GAF and SJA); at the edges of the main channels (ARE, CAR and VAG); in the main freshwater area highly organically enriched (RIO); in the area showing the highest levels of industrial pollution (LAR), and approximately in the middle of the longest channel (TOR) (Fig. 1).

Fishes were preserved by freezing and they were identified using taxonomic keys of Whitehead *et al.* (1986) and Bauchot & Pras (1987). The total fresh weight was measured with an electronic balance (And FX – 300).

Data Analysis

Fish were grouped by ecological guilds followed the classification of Elliott & Dewailly (1995): (1) ER, estuarine residents; (2) MJ, marine juveniles; (3) MS, marine seasonal; (4) FW, freshwater; (5) MA, marine adventitious; (6) CA, catadromous; and (7) AN, anadromous species.

Ten fish species were selected (Table 1) for this study consisting in the maximum of two most abundant species of each ecological guild, considering the total abundance of two years (Fig. 2).

Table 1 - Number of individuals and biomass (g) of fish sampled in 1999 and 2000 grouped by ecological guilds, according to Elliott & Dewailly (1995). Ten selected species are bold represented.

		Abundance		Biomass (g)	
Species	Code name	1999	2000	1999	2000
Estuarine Resident Species					
Ammodytes tobianus	Atob	9	-	102.1	-
Aphia minuta	Amin	48	5	9.3	4.5
Atherina boyeri	**Aboy**	**2,082**	**2,911**	**5,624.7**	**3,074.2**
Gobius ater	Gate	1	4	9.4	54.0
Gobius niger	Gnig	182	235	2,732.5	3,026.8
Gobius paganellus	Gpag	18	2	189.4	13.4
Mugil cephalus	Mcep	8	5	2,457.0	2,056.7
Nerophis ophidion	Noph	1	-	3.0	-
Platichthys flesus	Pfle	121	21	988.5	250.7
Pomatoschistus microps	**Pmic**	**526**	**338**	**443.4**	**192.3**
Pomatoschistus minutus	Pmin	75	47	69.3	105.1
Symphodus melops	Smel	-	1	-	14.8
Syngnathus acus	Sacu	203	200	729.3	1,063.8
Syngnathus typhle	Styp	6	6	15.2	2.6
Marine Juvenile Migrant Species					
Atherina presbyter	**Apre**	**1,011**	**1,225**	**7,078.3**	**6,896.0**
Chelidonichthys lucerna	Cluc	202	32	4,569.9	977.0
Dicentrarchus labrax	**Dlab**	**37**	**757**	**1,456.0**	**7,954.5**
Dicentrarchus punctatus	Dpun	5	-	34.4	-
Diplodus annularis	Dann	2	-	14.9	-
Diplodus sargus	Dsar	20	5	94.3	30.3
Diplodus vulgaris	Dvul	4	-	155.3	-
Pleuronectes platessa	Ppla	1	-	0.1	-
Scophthalmus rhombus	Srho	-	3	-	18.7
Solea senegalensis	Ssen	6	-	96.0	-
Solea solea	Ssol	3	-	41.6	-
Spondyliosoma cantharus	Scan	1	-	89.2	-
Trisopterus luscus	Tlus	4	-	10.4	-
Marine Seasonal Migrant Species					
Chelon labrosus	Clab	140	14	1,846.2	757.4
Ciliata mustela	Cmus	22	6	139.3	212.6
Engraulis encrasicolus	Eenc	352	334	359.6	715.4
Liza aurata	**Laur**	**4,273**	**5,092**	**45,624.5**	**50,237.4**
Sardina pilchardus	**Spil**	**8,739**	**9,478**	**13,683.9**	**13,694.3**

		Abundance		Biomass (g)	
Species	Code name	1999	2000	1999	2000
Freshwater Adventitious Species					
Carassius carassius	Ccar	-	3	-	1,346.4
Gambusia affinis	Gaff	-	4	-	1.9
Marine Adventitious Visitors					
Balistes carolinensis	Bcar	1	-	379.4	-
Boops boops	Bboo	2	1	89.8	0.4
Callionymus lyra	Clyr	12	6	211.1	116.9
Conger conger	Ccon	1	-	0.6	-
Deltentosteus quadrimaculatus	Dqua	1	-	9.0	-
Echiichthys vipera	Evip	-	1	-	19.2
Entelurus aequoraeus	Eaeq	-	1	-	0.8
Hyperoplus lanceolatus	Hlan	1	-	2.6	-
Labrus bergylta	Lber	2	-	140.1	-
Labrus merula	Lmer	1	-	59.4	-
Mullus surmuletus	Msur	21	12	893.3	598.9
Parablennius gattorugine	Pgat	8	10	37.8	45.0
Parablennius sanguinolentus	Psan	1	-	7.6	-
Pomatoschistus marmoratus	Pmar	7	-	22.5	-
Psetta maxima	Pmax	1	-	49.4	-
Scomber scombrus	Ssco	1	-	19.2	-
Solea lascaris	Slas	11	2	55.3	24.1
Sparus aurata	Saur	-	8	-	97.4
Symphodus bailloni	**Sbai**	**93**	**159**	**1,421.3**	**1,417.5**
Symphodus cinereus	Scin	1	1	51.5	4.3
Trachurus trachurus	Ttra	8	5	112.3	56.3
Catadromous Migrant Species					
Anguilla anguilla	**Aang**	**53**	**46**	**2,690.2**	**2,031.8**
Anadromous Migrant Species					
Alosa alosa	Aalo	4	3	287.1	57.5
Alosa fallax	Afal	21	24	551.2	344.1
Gasterosteus aculeatus	Gacu	-	13	-	182.5
Liza ramada	**Lram**	**627**	**1,227**	**10,587.2**	**11,375.7**
Liza saliens	**Lsal**	**444**	**10**	**6,270.6**	**267.1**

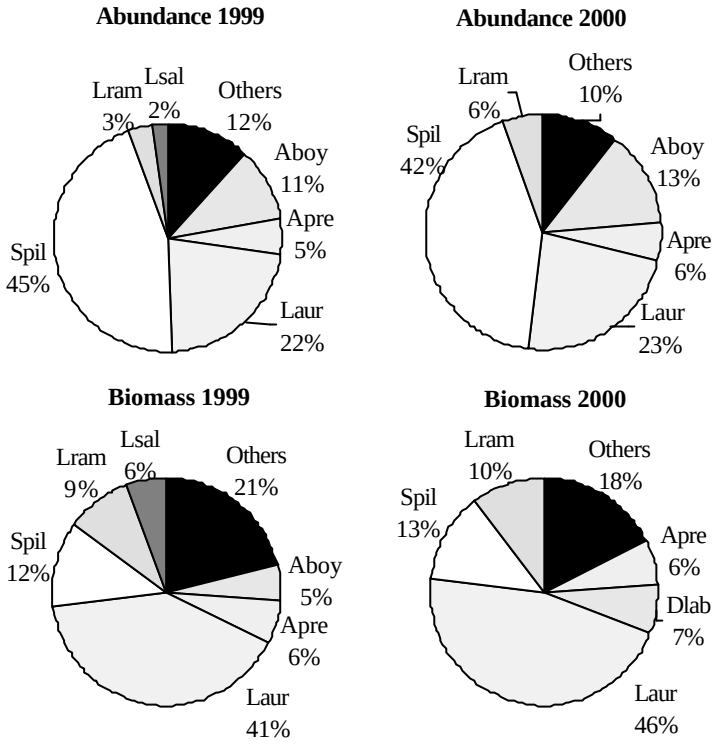

Fig. 2 - Pie charts of percentage of fish abundance and biomass for each year. Species code names are provided in table 1.

As the chosen of species with low abundance (less than 30 individuals in each year) could be questionable, only one species was selected for adventitious species and none for freshwater species. For catadromous species only one species is present in the lagoon.

The abundance (number of individuals) and biomass (wet weight individually recorded) distribution of species were established. The total percentage is referred to the individuals collected for one species in the lagoon, considering all the replicas, which indicates the tendency of a species to have a preferential area with respect to other areas in each year separately. This enabled the statistical significance of the distribution to be determined. Thus, two-way ANOVA without replication (Zar, 1984; Sokal & Rohlf, 1995) was carried out for any single species to test significant differences among the total abundance and total biomass of each species between sites in each year. The same statistical test was assessed to test significant differences among the abiotic parameters between sites and between months. Homogeneity of variances was tested using the Fmax test (Zar,

1984; Sokal and Rohlf, 1995). The abiotic analysis was completed using a t-test for the mean of each parameter of each site to determine if whether each abiotic parameter of each area of one year was different to the same area of the following year (Zar, 1984; Sokal & Rohlf, 1995).

Measurements of temperature (± 0.1 ºC) and dissolved oxygen (± 0.01 $mg.l^{-1}$) were taken with an oxygen meter (*Consort Z621*), salinity (± 0.1) with a refractometer (*Atago*), and pH (± 0.01) with a pH meter (*WTW 330/set – 2*). These parameters were only recorded at the water surface since preliminary fieldwork had shown water column differences were not significant (Rebelo, 1992). Turbidity (± 0.1 m) and depth (± 0.1 m) were measured with a Secchi disc after fish samplings at low tide of spring tides. This sampling protocol is consistent with previous surveys within the area (Rebelo, 1992; Pombo & Rebelo, 2002; Pombo *et al*., 2002a).

Analysis of the assemblage was established on the abundance and biomass data using a canonical correspondence analysis (CCA), which enabled the assemblage data to be assessed with respect to the environmental parameters (ter Brack, 1986). It gave an assessment of the relative importance of the parameters to the distribution of each species, as well as the factors of most importance to the assemblage structure in terms of abundance and biomass. The importance of the environmental factors is indicated by the relative length of vectors, the longer the vector the greater the influence on species distribution. In addition, the closer any two species are on the graph, the more similar their distribution; a similar relationship exists to the environmental parameters (ter Brack, 1986). The nature of canonical correspondence analysis dictates that any species highly influenced by two variables will be positioned along the axis created by two vectors rather than at the end of any single vector (ter Brack, 1986). These relationships were completed performing the Spearman Rank correlation analysis. This univariate non-parametric statistical technique enables the relationship between species abundance or biomass and abiotic factors to be analysed individually and also identifying which factor is responsible for maintaining structure of fish assemblages in each year (Sokal & Rohlf, 1995).

Diet Analysis

Stomachs contents were analysed to the lowest possible taxonomic level, according to Hayward & Ryland, (1998), with a stereomicroscope (*Olympus SZ60-PT*) (630x) and an optic microscope (*Olympus CH 30*) (1000x). The level of identification of food items is a function of the digestion stage of prey (Rosecchi & Nouaze, 1985). Crustaceans were identified from some parts of the body that allow their individualization, as the heads for amphipods, or cephalothoraxes or abdomina for mysids and decapods (Kara & Derbal, 1996). A small number of other items found in stomachs (e.g. molluscs shells and both larval and post larval crustaceans, and parasitic worms) were considered as miscellaneous or non-food items, probably ingested incidentally in normal feeding. Prey too digested for unequivocal identification to the lowest taxonomic level were assigned as n.i. (non-identified prey).The diet composition of each species was analysed for the frequency of occurrence of prey items. Frequency of occurrence of a given prey type was defined as the number of stomachs in which that prey occurs, expressed as a frequency of a total number of stomachs in which prey are present (Hyslop, 1980). Fish size will affect the prey taken (Wootton, 1990 *in* Marshall & Elliott, 1996), thus the size of each fish was noted and grouped as small, medium and large individuals in species which length was significant at this level. The size classes were determined using the maximum and minimum length of fish (total length). When the size classes included few data (less than 30 stomachs), only two groups were considered (small and large) or even no groups at all.

A Bray-Curtis similarity coefficient was performed based on the frequency of occurrence of prey to indicate the degree of feeding similarities and therefore the inter and intraspecific dietary interactions within the estuary.

Results

Assemblage Structure

A total of 61 teleost species was identified from 41,681 specimens (19,424 in the first year and 22,257 in the second year) with a total biomass of 222 Kg (113 kg in the first year and 109 kg in the second year) (Table 1). Of the 61 species

captured in the two years of sampling, only 33 species were common in two years, 20 species were exclusive to 1999 and 8 were exclusive to 2000.

The marine seasonal (68%) and estuarine resident species (17%) accounted for 85% of total abundance and 67% of total biomass collected during the whole period. Thirteen species were marine juvenile migrant species, comprising 8% of total numbers and 13% of total biomass. Twenty species were transient visitors of the lagoon, but they comprised a low number of the fish collected (1% of total individuals and 3% of total biomass). Only five species were anadromous and one catadromous accounting for 6% of total individuals and 13% of the total biomass, and only two freshwater species accounted 7 individuals that sporadically occurred in the lagoon (Table 1).

The ten selected species (bold represented in Table 1) comprised 92% of total abundance and 84 % of total biomass in the first year and 95% of total abundance and 89 % of total biomass in the second year. From the ten selected species, six were present in every sampling site: *S. pilchardus*, *L. aurata, A. boyeri*, *A. presbyter*, *D. labrax*, and *L. ramada*.

S. pilchardus was the most abundant species in both years comprising 44% of total numbers and 12% of total biomass (Fig. 2). *L. aurata*, also a marine seasonal species, comprised 22% of total numbers and 43% of total biomass (Fig. 2). The next two most abundant species, *A. boyeri* (resident) and *A. presbyter* (marine juvenile) accounted together for about 17% of total numbers and about 10% of total biomass.

During two subsequent years, the spatial distribution of most species was significantly different (Figs. 3 and 4). Only L. ramada, in the first year, and S. pilchardus, in the second year, did not show a significant difference distribution within the lagoon. The distribution of D. labrax and L. saliens was not statistically significant in both years (Fig. 3). The spatial distribution of biomass was quite similar to the abundance.

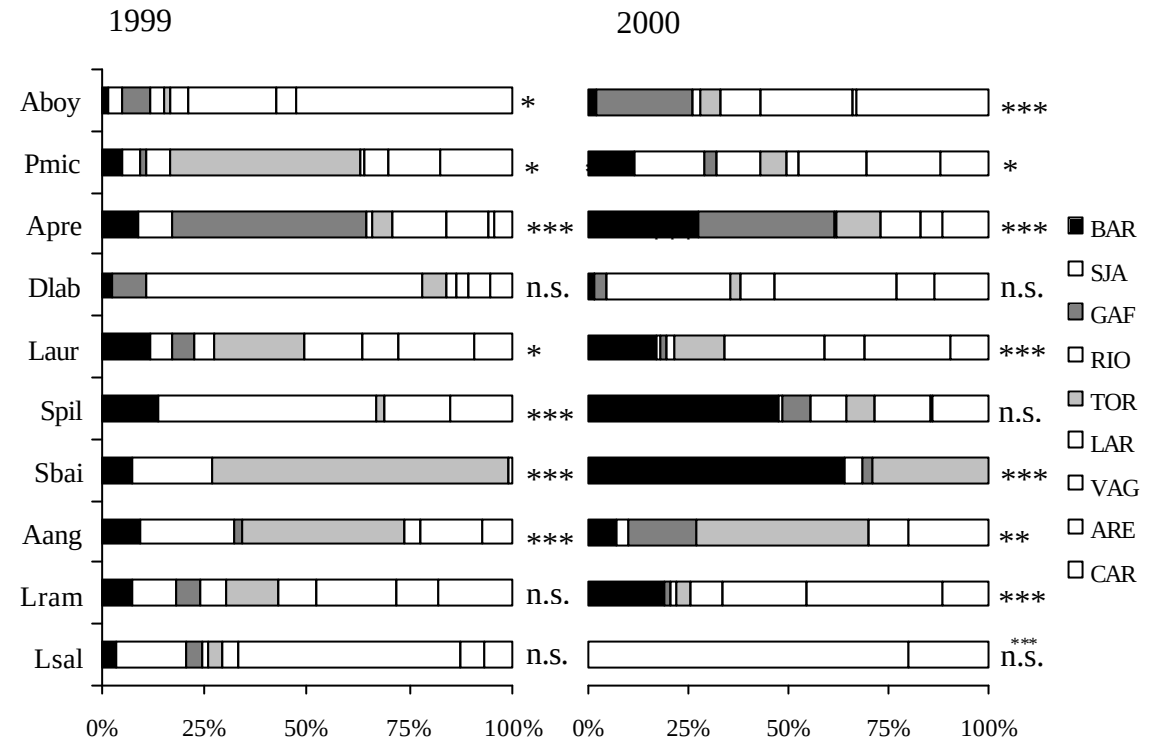

Fig. 3 - Distribution of species at each site, as a percentage of abundance over the study period, each graph corresponds to a determined sampling year. Species code names are provided in table 1, and sites abbreviations are explained in the text and shown in figure 1. Significantly differences of species abundance within sites are shown. n.s.: p>0.05; (*):p≤0.05; (**):p≤0.01; (***): p≤0.001.

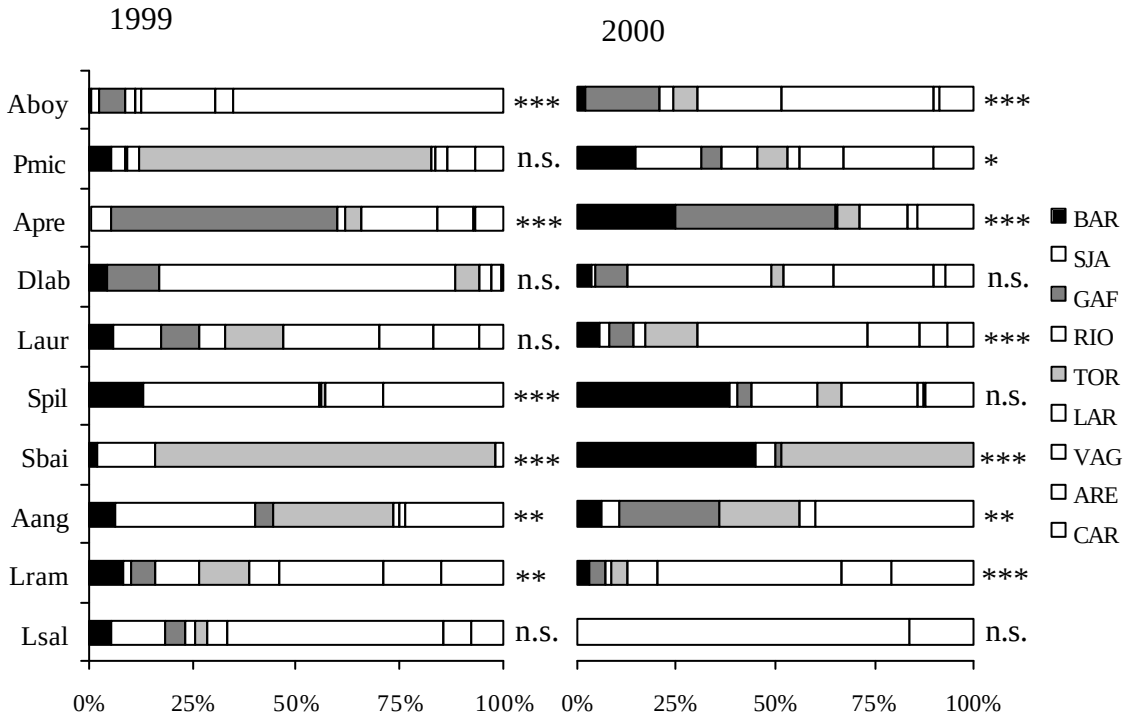

Fig. 4 - Distribution of species at each site, as a percentage of biomass over the study period, each graph corresponds to a determined sampling year. Species code names are provided in table 1, and sites abbreviations are explained in the text and shown in figure 1. Significantly differences of species abundance within sites are shown. n.s.: p>0.05; (*):p≤0.05; (**):p≤0.01; (***): p≤0.001.

Abiotic Parameters

The average, minimum and maximum values of the environmental data are clear in each year by site (Fig. 5) and by month (Fig. 6). Sampling sites are presented in the graphs according to the minor distance to the lagoon entrance. All the abiotic parameters analysed here, except temperature and dissolved oxygen, were spatially significantly different. On the other hand, only depth did not show seasonal statistically significant, as climatic factors were major determinants to the seasonal changes (Fig. 6).

The differences of temperature between the two sampling years were not statistically different ($p=0.801$). Temperature was markedly different along months, with higher values in summer months (27 ºC) and lower values in winter months (7.6 ºC) (Fig. 6).

Salinity varied from typically freshwater (ARE and RIO), brackish water (VAG, LAR and CAR), and marine water (BAR, SJA, GAF and TOR) (Fig. 5) close to the mouth of the lagoon. Salinity decreased gradually towards the upper reaches of the channels with a significant freshwater inflow, but in some remote shallow areas the circulation was reduced and concentration of salts may eventually occur during summer.

At times of maximum freshwater discharge resulting from continued rainy periods, in the second year, the salinity was severely decreased all over the lagoon although not significant ($p=0.570$) (Fig. 5). Dissolved oxygen varied from levels near the anoxia (4 $mg.l^{-1}$) in winter and oversaturated values (13 $mg.l^{-1}$) in summer, but those values were not significant within the lagoon. There was any statistically significant difference, in the whole lagoon, between the two years ($p=0.310$). pH changed significantly both temporally and spatially (Figs. 5 and 6), between acid (6.81) in the regions with higher chemical pollution problems, especially Hg concentrations, from the industrial complex of Estarreja (LAR) (Fig. 1) and alkaline (9.62) in the regions with urban effluents and farming activities (Ílhavo channel, Vouga River and Ovar channel) (VAG, RIO and CAR) (Fig. 1). There was a statistically difference ($p<0.001$) of pH values in all the sites, from the first to the second year, becoming more alkaline.

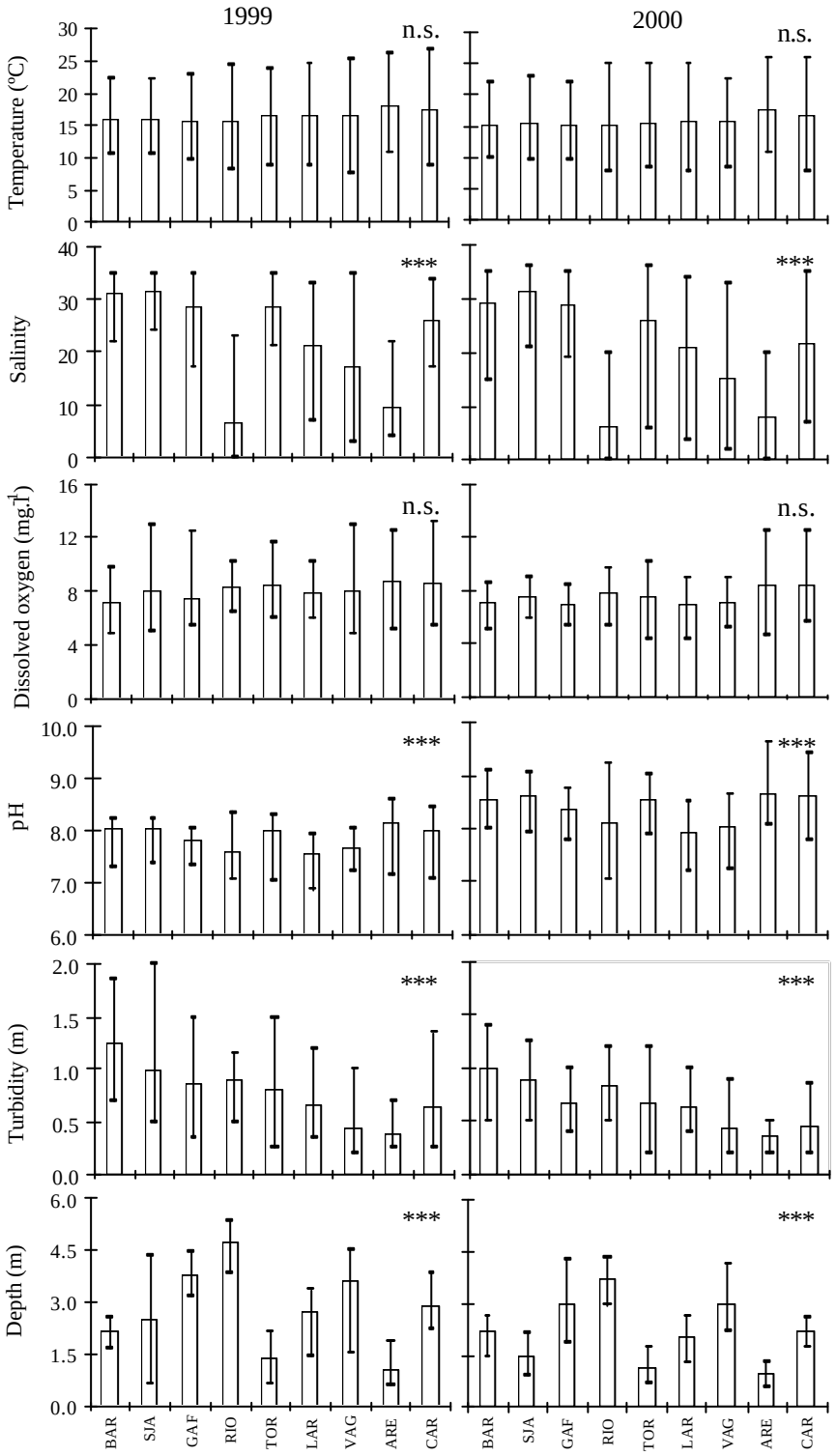

Fig. 5 - Minimum, average and maximum values of abiotic parameters by sampling sites, each column of graphs correspond to a determined sampling year. Site abbreviations are explained in the text and shown in Figure 1. Significantly differences of abiotic parameters between sites along months are shown. n.s.: p>0.05; (*):p≤0.05; (**):p≤0.01; (***): p≤0.001.

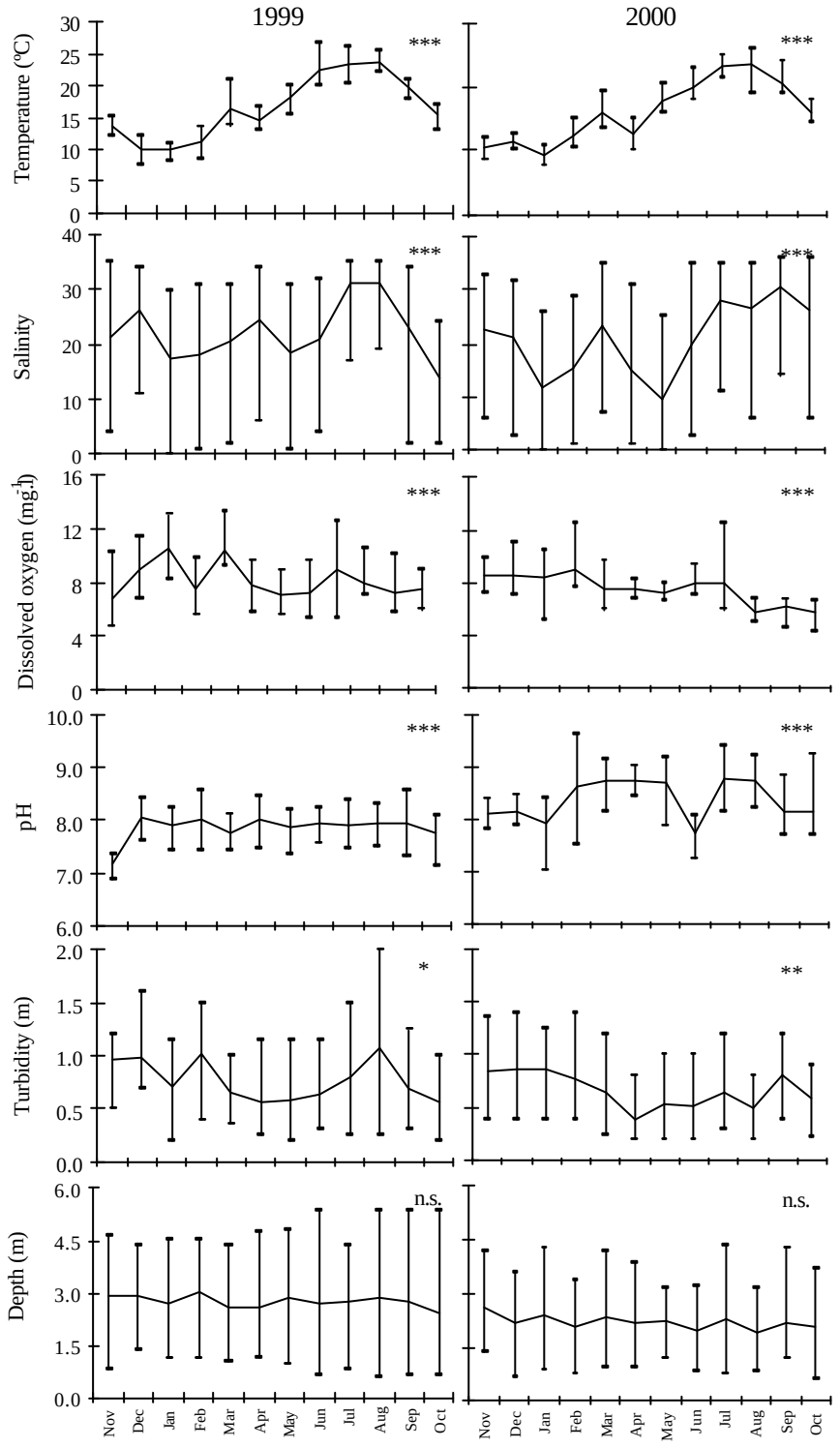

Fig. 6 - Minimum, average and maximum values of abiotic parameters by sampling months, in each year. Significantly differences of abiotic parameters between months are shown. n.s.: p>0.05; (*):p≤0.05; (**):p≤0.01; (***): p≤0.001.

Turbidity had both temporal and spatial variation varying between 20 cm, at the edges during summer and 2 m, near the mouth of the lagoon during winter (Figs. 5 and 6), where the currents are stronger. There was any significant variation between the first and the second year ($p=0.088$) in all the sites or months. Depth significantly varied ($p<0.001$) from the edges of channels (0.5 m) (ARE at south and TOR at north) to the inner regions of the lagoon (6 m) (RIO, VAG and LAR) (Fig. 5) but that difference was not significant during months in each year (Fig. 6). There was a significantly decrease of depth ($p<0.001$) between the two years of fish sampling in most sites (with the exception of the shallow sites - ARE, BAR and TOR).

Environmental Influences on Fish Distribution

The relative importance of the measured environmental factors to the fish abundance and biomass is shown in figures 7 and 8, as determined by canonical correspondence analysis. Only axes 1 and 2 were plotted as they accounted for 82% and 80% of the total variability, respectively in each year, for the abundance data; and 71% and 81% in each year, for the biomass data.

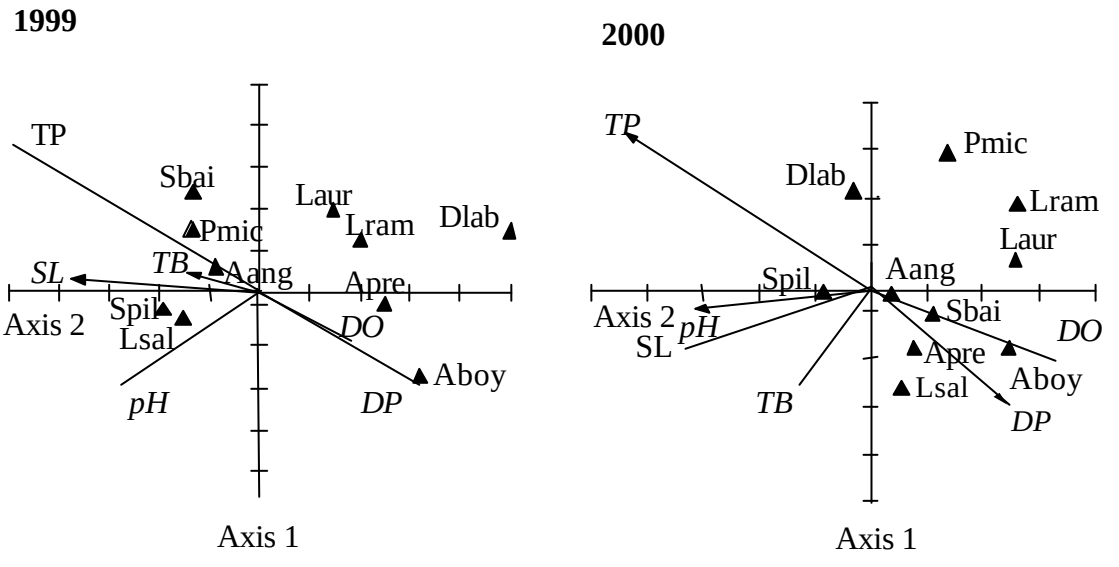

Fig. 7 - CCA ordination diagram of Ria de Aveiro dominant fish abundance with environmental factors represented by arrows: temperature (TP); salinity (SL); dissolved oxygen (DO); pH (pH); turbidity (TB) and depth (DP). Species codes are provided in table 1.

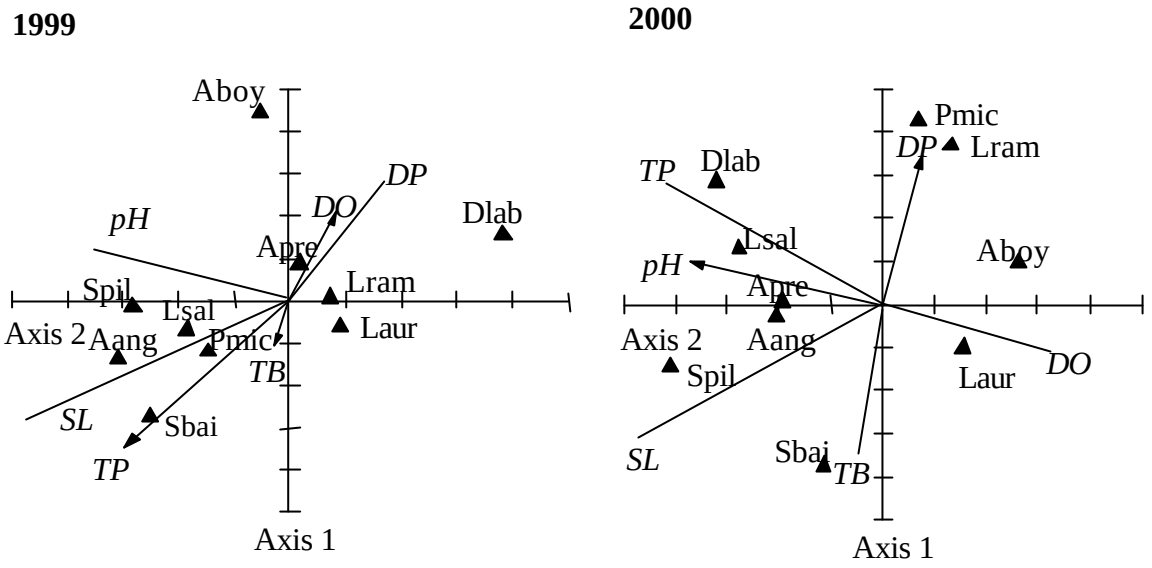

Fig. 8 - CCA ordination diagram of Ria de Aveiro dominant fish biomass with environmental factors represented by arrows: temperature (TP); salinity (SL); dissolved oxygen (DO); pH (pH); turbidity (TB) and depth (DP). Species codes are provided in table 1.

The relative lengths of the vectors indicate that temperature was the most important abiotic factor in the abundance distribution of species (Fig. 7), reflecting the seasonally varying nature of the assemblage and proving to be the best predictor of total abundance. The majority of species had a higher abundance above average temperature and occur in the areas near the mouth of the lagoon, where the salinity and depth are also high, especially the adventitious and seasonal migrant species. Temperature was positively correlated to abundance of *A. anguilla* in the first year, and *S. pilchardus* and *D. labrax* in the second year, and negatively correlated to *L. ramada* in the second year (Table 2 and Fig. 7).

Table 2 - Correlation between fish abundance and environmental factors in 1999 and 2000. Species codes are provided in table 1. TP - temperature (ºC); SL- salinity; OD- dissolved oxygen ($mg.l^{-1}$); pH- pH; TB - turbidity (m); DP - depth (m). Significantly correlations between species abundance and abiotic parameters are shown. Blanks: $p>0.05$, (+ or -): $p\leq0.05$, (++ or --): $p\leq0.01$, (+++ or ---): $p\leq0.001$.

	Aboy		Pmic		Apre		Dlab		Laur		Spil		Sbai		Aang		Lram		Lsal	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
TP								+++			+	+++			++			-		
SL					+++	+++		+			++	+++	+	+++		+++				
DO				+			+	---				---								
pH				+											++					-
TB					-	-								+++			-	---		-
DP		++							--	---			---	--	---					

Analyses of the biomass data (Fig. 8) gave a slightly different grouping of species around the environmental variables and the relative importance of variables was also different. Salinity was found to be the most important abiotic factor affecting the fish biomass; with temperature also showing influence on the distribution of fish biomass. Salinity and temperature positively correlated to *S. pilchardus* and *A. anguilla*, which occurred with high biomass near the mouth of the lagoon and in the middle of the main channel (Fig. 4) with high salinity (Fig. 5), especially in summer, with high temperature.

The positions of turbidity, depth, dissolved oxygen and pH vectors may result in a skewing of the species distribution. The turbidity negatively influenced the abundance distribution of *A. presbyter* and *L. ramada* in both years (Table 2) but only influenced the biomass of the latter species (Table 3).

Table 3 - Correlation between fish biomass and environmental factors in 1999 and 2000. Species codes are provided in table 1. TP- temperature (ºC); SL- salinity; OD- dissolved oxygen (mg.l-1); pH- pH; TB- turbidity (m); DP- depth (m). Significantly correlations between species biomass and abiotic parameters are shown. Blanks: $p>0.05$, (+ or -): $p\leq0.05$, (++ or --): $p\leq0.01$, (+++ or ---): $p\leq0.001$.

	Aboy		Pmic		Apre		Dlab		Laur		Spil		Sbai		Aang		Lram		Lsal	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
TP								+++			+	+++				++		-		
SL						+++		++			++	+++	+	+++	++	+++				
DO							+	---				---								
pH				+						-			+			++				-
TB														+++			---	---		-
DP		+	++			+							---	--	---					

Depth negatively influenced the distribution (abundance and biomass) of *S. bailloni* and *A. anguilla*, and positively influenced the distribution of *A. boyeri* (Tables 2 and 3). In the first year, dissolved oxygen positively influenced the abundance and biomass of *D. labrax*, and, in the second year, when the oxygen was lower, negatively influenced the distribution of *D. labrax* and *S. pilchardus* (Tables 2 and 3). The pH was positively correlated to the distribution (abundance and biomass) of *S. bailloni* and *A. anguilla*, in the first year, but when pH increases, in the second year, pH was only positively correlated to *P. microps* and negatively correlated to *L. saliens* (Tables 2 and 3).

Feeding Habits

The prey frequency of occurrence indicated that several feeding groups are present in fish species (Table 4).

Table 4 - Food items frequency of occurrence on abundant species during 1999. Species abbreviations are explained in table 1, and guild abbreviations are explained in the text.

Food items	ER		MJ		MS		MA	CA	AN	
	Aboy	Pmic	Dlab	Apre	Laur	Spil	Sbai	Aang	Lram	Lsal
Phylum Annelida										
Polychaeta	7.4	2.8	30.0	10.1	1.3	1.3	1.2	12.3		1.4
Annelida n.i.	31.5		10.0	29.7	0.3	0.7	1.2	6.2	0.3	0.7
Phylum Mollusca										
Gastropoda	4.5	1.9		7.3	0.8	2.6		2.5	0.6	
Bivalvia	9.9	4.6		20.0	1.8	3.9	4.8	1.2	3.2	0.7
Phylum Artropoda										
Chironomidae					0.2				0.3	
Formicidae				0.8						
Insecta larva	10.0		3.3	7.3	2.0	2.0	1.2	2.5	1.3	0.7
Insecta n.i.	11.2	6.5		17.4	3.7	2.6	2.4	3.7	3.2	0.7
Phylum Crustacea										
Microcrustacea										
Branchiopoda					0.1					
Cumacea				0.6		1.3				
Ostracoda	1.7	2.8		1.7	0.2					0.7
Copepoda	7.9	2.8	3.3	4.5	2.7	8.6	1.2	2.5	3.8	2.1
Crustacea larvae				0.3	0.1	3.3	3.6			
Small benthic crustacea										
Gnatia sp.				0.6						
Idotea sp.	1.2	2.8		1.4	0.2	0.7	22.9	1.2		
Sphaeroma sp.	31.0	10.2	20.0	24.7	0.4	0.7	4.8	6.2	0.3	0.7
Isopoda n.i.	0.4	1.9		0.8		0.7	7.2		0.3	
Ampithoe sp.				0.3			1.2			
Corophium sp.		0.9		0.3			3.6			
Gammarus sp.		1.9	6.7	0.6	0.1		2.4	3.7		
Amphipoda n.i.	2.5	7.4	26.7	4.5	0.1	2.6	24.1	6.2		
Small pelagic crustacea										
Gastrosaccus sp.	0.4		3.3	0.3	0.1					
Neomysis sp.				0.3	0.3					
Praunus sp.	0.8			0.6						
Paramysis sp.					0.1					
Mysidacea n.i.	6.6	6.5	36.7	8.7	0.6	3.9		12.3		
Macrocrustacea										
Crangon crangon	0.8	0.9	13.3	1.1				3.7	0.3	
Carcinus sp.			3.3					12.8		
Decapoda n.i.			6.7	0.6		0.7	1.2	3.7		
Crustacea n.i.	12.4	13.9	13.3	13.8	0.6	4.6	7.2	6.2	0.6	
Algae	8.3	1.9	3.3	6.5	8.1	1.3		12.3	13.9	9.2
Detritus	4.1	38.9		4.5	75.1	54.6	4.8	2.5	91.2	95.7
Eggs n.i.	5.4			5.3	0.1			1.2	0.3	0.7
Fish		5.6	3.3		1.1	1.3	4.8	3.7	0.6	
Size length (cm TL)	2-12	1-9	3-20	5-15	2-27	4-16	4-16	6-63	2-31	2-120
No. Non-empty stomachs	246	108	30	355	972	114	46	39	317	141

The main food items of five species (*L. saliens*, *L. ramada*, *L. aurata*, *S. pilchardus*, and *P. microps*) were detritus. Annelida n.i. and *Sphaeroma* sp. (Isopoda) were the most representative food items for both Atherinids; all the other categories were occasional prey, i.e. prey were rarely consumed by a large number of individuals. Amphipoda n.i. and *Idotea* sp. were the most important prey for *S. bailloni*, and algae, mysidacea n.i. and polychaeta were the most important prey for *A. anguilla*. *D. labrax* showed several important food items (mysidacea n.i., polychaeta, amphipoda n.i., and *Sphaeroma* sp.) although the species can feed opportunistically on other organisms (Table 4).

Classification of samples by cluster analysis of fish food preference identified several assemblages that shared a number of common key prey (Fig. 9).

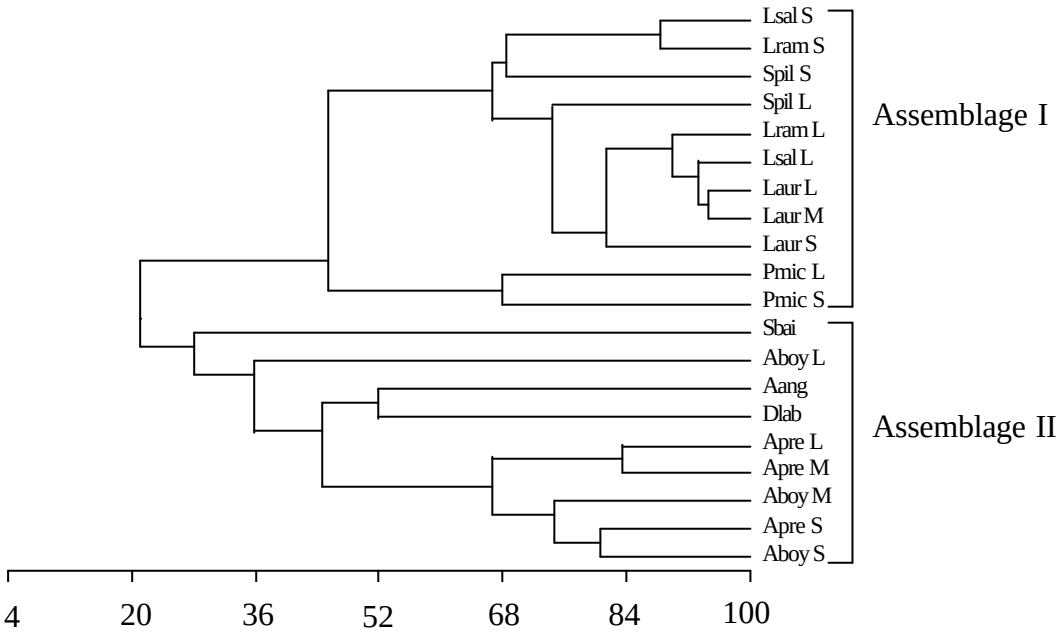

Fig. 9 - Bray-Curtis similarity of frequency of occurrence of stomach contents of fish during 1999. Species code names are provided in table 1. Size range and number of non-empty stomachs are provided in table 5. S- small, M- medium, L- large.

Cluster analysis distinguished two main groups at the 25% level of Bray-Curtis similarity (Fig. 9). Assemblage I included all the fish whose diet was strongly dominated by detritus (*L. saliens*, *L. ramada*, *L. aurata*, *S. pilchardus*, and *P. microps*) and assemblage II included fish with more than one dominant prey (*A. boyeri*, *A. presbyter*, *A. anguilla*., *D. labrax* and *S. bailloni*) (Fig. 9).

Considering assemblage I, small individuals of mullets (*L. saliens* and *L. ramada*) (less than 12 cm) and *S. pilchardus* (less than 7 cm) classed together at 69% of similarity, showing preference on copepods, detritus and algae. The second group, including all the sizes of *L. aurata* and large sizes of the other two mullets (more than 12 cm) and *S. pilchardus* (more than 7 cm) also showed similarities in diet (74 % of similarity), feeding largely on detritus and feeding occasionally on other prey. Large and small *P. microps*, classed together at 68 % of similarity, showed preference for microcrustaceans (cumaceans) and small crustaceans (mysidacea and *Sphaeroma* sp.) besides detritus.

Considering assemblage II, the two atherinids species were classed together at 67% of similarity (Fig. 9). The diet of smaller individuals (less than 8 cm), which included *A. presbyter* S and *A. boyeri* S, and M, (Table 5) was based on small benthic crustaceans especially *Sphaeroma* sp. Larger individuals (more than 8 cm) of *A. presbyter* classed together at 84% of similarity, feed mainly on annelids, bivalves, and crustaceans (Table 4), while larger individuals of *A. boyeri* feed mainly on insects.

Table 5 - The size range (cm TL) and the number of non-empty stomachs analysed, between parentheses, for each species. Length groups were established according to size length of species. The length groups with less than 30 stomachs were not considered for the analyses of inter- and intraspecific competition.

Size range (cm TL) (No. non-empty stomachs)	Aboy	Pmic	Apre	Laur	Spil	Lram	Lsal
Small (S)	<6 (64)	<4 (52)	<8 (78)	<10 (351)	<7 (65)	<12 (164)	<12 (83)
Medium (M)	6-8 (142)		8-11 (157)	10-13 (355)			
Large (L)	>8 (40)	=4 (56)	>11 (108)	>13 (266)	=7 (49)	=12 (153)	=12 (58)

The diet of *A. anguilla* and *D. labrax*, classed together at 52% of similarity, was very diverse and mainly based on small benthic and pelagic crustaceans, especially mysids, amphipods and *Sphaeroma* sp. Finally, *S. bailloni*, showing a different diet and preferring small benthic crustaceans, as amphipoda n.i. and *Idotea* sp., classed together with the other species at 27% of similarity.

Discussion

Both fish abundance and species diversity can provide managers with a good indication of the health of a particular system (Whitfield, 1996). The estuarine coastal lagoon, Ria de Aveiro, is highly influenced by the adjacent abiotic variations, which affect the recruitment, distribution and the survival of fish species. Most fish found in estuaries and coastal lagoons use these areas for feeding and growth, since these areas provide protection from predators and ensure high food availability for a number of marine species and juvenile teleosts (Kuo *et al*., 2001).

In the present study, most fish abundance and biomass changed significantly between sites, showing preference for some specific areas with particular environmental characteristics. The abiotic factors analysed here strongly influenced fish assemblages but could not fully explain differences between assemblages, as it is difficult to analyse individually each abiotic factor form the others as they interact with each other. Other factors such as the influence of tides, velocity and streams and also the human impacts (Marshall & Elliott, 1996, 1998) likely have a great importance on fish abundance and biomass distribution. The aggregation of lagoon-opportunistic and lagoon-dependent species to restrict areas may make the populations more vulnerable to a number of environmental and human perturbations such as point-source pollution (organic and chemical spills), toxic algal blooms or heavy fishing intensity (Jones *et al*., 1996).

Temperature was found to be the most important abiotic factor affecting the abundance distribution of fish assemblage, proving to be the best predictor of total abundance, which is more related to fish movements from the sea to the lagoon (and *vice-versa*) than with migration within the lagoon. Similar results were observed in various regions (Jones *et al*., 1996; Marshall & Elliott, 1998; Kuo *et al*., 2001). Water temperature influenced the fish fauna of the lagoon during both spring-summer and autumn-winter, but in opposite ways. For the warmer spring-summer period, with average temperatures higher than 15ºC, fish abundance and biomass were high in the whole lagoon. On the other hand, during the cooler autumn-winter period, the water temperatures at all sites were above average temperature and most of the species markedly decreased in abundance and

occurred at the areas near the mouth of the lagoon, especially *A. anguilla*, *S. pilchardus* and *D. labrax* that were positively correlated to temperature.

Salinity significantly varied seasonally and spatially between 0 and 35, with higher salinities in the entrance, inner and mid parts of the lagoon during warmer months and with lower salinities near the major rivers influence during winter. The seasonal variation of salinity in the whole lagoon was strongly related to rainfall. At times of maximum freshwater discharge resulting from rainy periods, as occurred in 2000 in spring, the salinity severely decreased all over the lagoon. However, the occurrence of some species throughout the lagoon, as *A. boyeri* and *P. microps*, is typical of resident species, irrespective of salinity, which are highly tolerant of variable environmental conditions (Elliott & Taylor, 1989).

The biomass distributions is affected by the movements of fish within the lagoon, which migrate to deeper regions of the lagoon, as a strategy of protection against predators and minimization of food competition with others fish species (Harley *et al*., 2001) and also the migrations between the sea and the lagoon for reproduction reasons. Thus, salinity was found to be the most important abiotic factor affecting fish biomass, as occurs in the Humber estuary, U.K. (Marshall & Elliott, 1998), with temperature also having important influence on fish biomass distribution. The abiotic conditions diverged within sites and the low biomass of all fish species observed in Areão (Mira channel) (8.5 kg in the first year and 6.1 kg in the second year) contrast with the high biomass in Carregal (Ovar channel) (16.7 kg in the first year and 11.5 kg in the second year). While Mira channel is like a small estuary, Ovar channel behaves as a semi-enclosed coastal lagoon (Cunha, 1999) with high temperature and salinity levels recorded seasonally in the seagrass areas at the most confined regions.

Over the last decades, there has been an increasing concern about men's impact on the ecosystem (Van Leeuwen *et al*., 1994). The marine environment may potentially be affected by a variety of human activities, both direct and indirect, such as coastal engineering works, pollution, eutrophication, fisheries and global warming. In order to analyse the possible influences of human activities, knowledge on the dynamics of the marine ecosystem is necessary. Several natural and anthropogenic factors may have a direct influence on the environmental and on

food resources, distribution, growth, survival and behaviour of the fish present (Perez-Ruzafa *et al*., 1991; Whitfield, 1996). Some of the effects of dredging and the enlargement of communication channel with the open sea are the colonization by new marine species. On the other hand, changes in the sediments may result in fall in the fisheries stocks of some species (Perez-Ruzafa *et al*., 1991). In Ria de Aveiro, dredging occurred in the previous years, between October 1997 and May 1998, with records of 1 510 000 m^3 of extracted sediment from the main channels (Ovar, Murtosa, and Mira) (JAPA, 1993). This enlarged the tidal-range and the water removal, possibly allowing a large variety of fish species, especially marine adventitious species, to enter the lagoon (Pombo *et al*., 2002a). After the dredging, channels with a greater depth and therefore a greater potential mobility of the fish in the water column possibly induced the entrance of typically marine species from the adjacent ocean (Pombo *et al*., 2002a). During the sampling period analysed here, depth significantly decreased, while pH significantly increased, from the first to the second year. The strong rainfalls in 2000, and consequently the raised flows of water leaded to a bedstead deepen, transporting sediments from one region to another, changing substantially the lagoon sediments and consequently modifying the distribution of fish fauna (Perez-Ruzafa *et al*., 1991; Harley *et al*., 2001).

The dietary analysis enabled a further assessment of biological interactions of fish within the lagoon. While intraspecific comparisons according to size are not possible for all the species, interspecific interactions can be assessed. As the seasonal differences in the distribution of the first group of species are shown by negative relationships with different parameters, potential competition may be avoided by the seasonal separation of estuarine use. *S. pilchardus* being more abundant in regions near the mouth of the lagoon, to easily go back to the sea, the diet may not limit these populations, which is highly based on detritus but with a wide range on other organisms. *P. microps*, with a wide distribution within the lagoon, a weak correlation to the environmental parameters, and whose diet is highly diverse, may indicate that food may not limit the abundance of the species.

In the other group of fish, the two atherinids species showed a strong selective spatial distribution with the age and a different importance of each food item (Fernandez-Delgado *et al*., 1988, Creech, 1992, Leonardos & Sinis, 2000; Pombo

et al., 2002b), suggesting that they do not compete for the existing food, which was based on small benthic crustaceans especially *Sphaeroma* sp. (Isopoda) for younger individuals, and annelids, bivalves, insects and crustaceans for older individuals. *D. labrax* and *A. anguilla*, whose diet was mainly based on small pelagic and benthic crustaceans, and polychaets, did not show overlapping spatial distributions (Pombo *et al*., 2002c). *D. labrax* was highly distributed near the main river influence, while *A. anguilla*, having a high preference for the main channel and for the upper reaches of Ovar channel. The extensive sea grass in this channel probably contributed to the extremely high abundance recorded in this area, as it provides an additional source of food and shelter (Nagle, 1968; Nienhuis & Van Ierland, 1978 *in* Cunha, 1999).

The most productive areas within the lagoon appear to be related to finer sediments (upper reaches of Ovar Channel and middle reaches of Mira Channel) (Cunha, 1999). The high organic content and food availability must be substantial and determinant to the fish abundance observed here. In fact, all the species colonized the north edges of Ovar channel, and most of them colonized the Mira channel, except *S. bailloni*. This marine adventitious species colonizes the lagoon occasionally in few restricted areas, especially at the mouth of the lagoon, as they are opportunistic and feed on a wide range of food items not feeding on mysids and preferring amphipods and isopods (*Idotea* sp.). In fact, amphipods dominated the upper reaches' assemblage in Ovar channel whereas mysids were dominant in the lower and middle reaches of the channel and all over the Mira channel (Cunha, 1999). On the whole, mysids were dominant during winter and spring and amphipods during summer and autumn (Cunha, 1999). Isopods had an important portion of the community in the upper reaches of both channels during all the year (Cunha, 1999).

The relationships between environmental variables, especially temperature and salinity, and the abundance of different species, are partly the result of seasonal migrations into and out of the lagoon, and, for resident species, recruitment and mortality within the area. This will serve to obscure some of the trends observed with respect to environmental influences, as biological factors may dominate and occur irrespective of water parameters (Marshall & Elliott,

1996). The most important biological relationships are the competition for food and space and the presence of a stock for recruitment (Marshall & Elliott, 1996).

The increasing abundance of benthic and demersal species along the years in the lagoon (Pombo *et al*., 2002a), and their dependence on the benthic fauna, dictates that hydrodynamics and sediment transport regime, responsible for the distribution of sediment environments, have an outstanding role in structuring the suprabenthic community in Ria de Aveiro (Cunha, 1999). However, in this study of diet, only restrict overlapping spatial distributions of fish with the food groups are evident. More information is required on the availability of prey organisms in the whole lagoon, and on spatial and temporal diet and feeding habits to be sure of their effectiveness influence on the distribution of fishes within the lagoon.

Ria de Aveiro shows a dynamic and a variable environment, with abiotic factors significant variations, where most species occur in areas over average of temperatures and salinities. The nursery function of lagoons ((Rogers *et al*., 1984 in Rakocinski *et al*., 1996; Elliott & Hemingway, 2002) and, as shown by temperature patterns in the Ria de Aveiro, seasonal changes appear to have greater importance to the fish assemblage than position within the lagoon. Feeding analysis indicates that the fish species are mostly dependent on detritus, small benthic and pelagic crustaceans. The low spatial segregation of fish in relation to feeding preference suggest that, in a food-rich lagoon as Ria de Aveiro, the environmental-biological interactions could have a greater effect on fish distribution than do biological interactions.

Acknowledgements

The authors would like to thank the University of Aveiro, the Foundation of Science and Technology and the European Social Fund for their financial support for this study. The authors are also very grateful to all the students who helped in the field and laboratory work.

References

Barrosa, J.O. 1980. A Ria de Aveiro e a sua influência na economia da região. *Recurs. Hidric.*, 1 (3): 83-96.

Bauchot, M.L. & Pras, A. 1987. *Guía de los peces de mar de España y de Europa.* Ediciones Omega, Barcelona.

Blaber, S.J.M. & Blaber, T.G. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *J. Fish Biol.*, 17: 143-162.

Borrego, C.; Cruz, M.M. & Gonçalves, P. 1994. *Estudo de avaliação da vulnerabilidade da capacidade de recepção das águas costeiras em Portugal. Relatório R 3.2. Meios receptores e suas características: (Be 1) - Ria de Aveiro, Pateira de Fermentelos e Barrinha de Mira.* Projecto n. 13/94. IDAD, Aveiro.

Creech, S. 1992. A multivariate morphometric investigation of *Atherina boyeri* Risso, 1810 and *A. presbyter* Cuvier, 1829 (Teleostei: Atherinidae): morphometric evidence in support of the two species. *J. Fish Biol*., 41: 341-353.

Cunha, M.M.P.R. 1999. *Peracaridan crustacea in Ria de Aveiro (NW Portugal): taxonomic composition and spatio-temporal structure of the assemblages; life history and secondary production of Corophium multisetosum Stock, 1952 (Amphipoda, Corophiidae).* Ph. D. Thesis, Univ. Aveiro, Portugal.

Duffy-Anderson, J.T. & Able, K.W. 1999. Effects of municipal piers on the growth of juvenile fishes in the Hudson River estuary: a case across a pier edge. *Mar. Biol.*, 133: 409-418.

Elliott, M & Hemingway, K.L. (Eds.). 2002. *Fishes in Estuaries*. Blackwell Science, Oxford.

Elliott, M. & Taylor, C.J.L.. 1989. The structure and functioning of an estuarine/marine fish community in the Forth estuary, Scotland. In: Proceedings of the 21st European Marine Biologists Symposium, Polish Academy of Sciences Institute of Oceanology (Eds.), Warsaw: 227-240.

Elliott, M. & Dewailly, F. 1995. The structure and components of European estuarine fish assemblages. *Neth. J. Aquat. Ecol.*, 29 (3-4): 397-417.

Elliott, M.; Griffiths, A.H. & Taylor, C.J.L. 1988. The role of fish studies in estuarine pollution assessment. *J. Fish Biol.,* 33 (Supplement A): 51-61.

Fernandez-Delgado, C.; Hernando, J.A.; Herrera, M. & Bellido, M. 1988. Life history patterns of the sand smelt *Atherina boyeri* Risso 1810 in the estuary of the Guadalquivir River, Spain. *Estuar. Coast. Shelf Sci.*, 27: 697-706.

Haedrich, R.L. 1983. Estuarine fishes. In: Ketchum, B. (Ed.), *Estuaries and enclosed Seas*. Elsevier. Amsterdam. 183-207 p.

Hall, A. 1980. Water quality problems in Ria de Aveiro. A preliminary assessment. In: Seminar on actual problems of Oceanography in Portugal, Lisboa, 20-21 Nov., 1980: 159-169.

Harley, X.; Koubbi, P. & Grioche, A. 2001. Ecology of plaice (*Pleuronectes platessa*) in fish assemblages of beaches of the Opale coast (North of France) during spring 1977. *Cybium*, 25 (1): 67-80.

Hayward, P.J. & Ryland, J.S. 1998. *Handbook of the Marine Fauna of north west*. Oxford University press, United States.

Hyslop, E.J. 1980. Stomach contents analyses – a review of the methods and their application. *J. Fish Biol.,* 17: 411-429.

Irigoien, X.; Post, J.; Castel, J.; Pfeiffer, K.F. & Hellmann, B. 1999. Nycthemeral variations of the dissolved oxygen concentration in the turbidity maximum of three European estuaries: biological vs. physical processes. *Journal of Marine Systems*, 22: 173-177.

JAPA. 1993. *Estudo de impacto ambiental – desassoreamento da Ria de Aveiro, 1ª fase*. Junta Autónoma do Porto de Aveiro. Edição do Porto de Aveiro, Aveiro.

Jones, G.K.; Baker, J.L.; Edyvane, K. & Wright, G.J. 1996. Nearshore fish community of the Port River-Baker Inlet Estuary, South Australia. I. Effect of the thermal effluent on the fish community structure, and distribution and growth of economically important fish species. *Mar. Freshwater Res.*, 47: 785-99.

Kara, M.H. & Derbal, F. 1996. Régime alimentaire du Loup *Dicentrarchus labrax* (Poisson, Moronidé) du Golfe d'Annaba, Algérie. *Annales de l'Institut Océanographique*, 72 (2): 185-194.

Kuo, S.-R. ; Lin, H.-J. & Shao, K.-T. 2001. Seasonal changes in abundance and composition of the fish assemblage in Chiku lagoon, Southwestern Taiwan. *Bull. Mar. Sci.*, 68 (1): 85-99.

Leonardos, I. & Sinis, A. 2000. Age, growth and mortality of *Atherina boyeri* Risso, 1810 (Pisces: Atherinidae) in the Mesolongi and Etolikon lagoons (W. Greece). *Fish. Res.,* 45: 81-91.

Lima, C. 1986. *Impacto da poluição por mercúrio nos organismos aquáticos da Ria de Aveiro.* Relatórios do Instituto Nacional de Investigação das Pescas 66, Aveiro.

Lucas, M.F.; Caldeira, M.T.; Hall, A.; Duarte, A.C. & Lima, C. 1986. Distribution of mercury in the sediments and fishes of the lagoon of Aveiro, Portugal. *Water Sci. Technol.,* 18: 141-148.

Marchand, J. 1993. The influence of seasonal salinity and turbidity maximum variations on the nursery function of the Loire estuary (France). *Neth. J. Aquat. Ecol.,* 27: 427-436.

Marshall, S. & Elliott, M. 1996. The structure of the fish assemblage in the Humber Estuary, U.K. *Publ. Espec. Inst. Esp. Oceanogr.,* 21: 231-242.

Marshall, S. & Elliott, M. 1998. Environmental influences on the fish assemblage of the Humber Estuary, U.K. *Estuar., Coast. Shelf Sci.,* 46: 175-184.

Morgado, F.M.R. 1997. Ecologia da zooplâncton da Ria de Aveiro - caracterização espácio-temporal, transporte longitudinal e dinâmica tidal, nictemeral e lunar. Ph.D. Thesis, Univ. Aveiro, Portugal.

Nagle, J.S. 1968. Distribution of the epibiota of macroepibenthic plants. *Contrib. Mar. Sci.,* 13: 105-144.

Nienhuis, P.H. & Van Ierland, E.T. 1978. Consumption of eelgrass, *Zoostera marina*, by birds and invertebrates during the growing season in Lake Grevenlingen (SW Netherlands). *Neth. J. Sea Res*., 12 (2): 180-194.

Perez- Ruzafa, A.; Marcos-Diego, C. & Rós, J.D. 1991. Environmental and biological changes related to recent human activities in the Mar Menor (SE of Spain). Mar. Pollut. Bull., 23: 747-751.

Perry, R.I.; Stocker, M. & Fargo, J. 1994. Environmental effects on the distribution of groundfish in Hecate Strait, British Columbia. *Can. J. Fish. Aquat. Sci*., 51: 1401-09.

Pombo, L. & Rebelo, J.E. 2002. Spatial and temporal organisation of a coastal lagoon fish community – Ria de Aveiro, Portugal. *Cybium*, 26 (3): 185-196.

Pombo, L.; Elliott, M. & Rebelo, J.E. 2002 a. Changes in the fish fauna of the Ria de Aveiro estuarine lagoon (Portugal) during the twentieth century. *J. Fish Biol.*, 61 (Supplement A): 167-181.

Pombo, L; Dias, C.& Rebelo, J.E. 2002 b. Diet comparison between *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal. *Rev. Biol. (Lisboa)*, 20: 59-72.

Pombo, L.; Lopes, C. & Rebelo, J.E. 2002 c. A comparison study on the age and growth of *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal. *Rev. Biol. (Lisboa)*, 20: 47-58.

Pomfret, J.R.; M. Elliott; O'Reilly, M.G. & Philips, S. 1991. Spatial and temporal patterns in the fish communities in the U.K. North Sea estuaries. In: Elliott, M. & Ducrotoy, J-P. (Eds.), *Estuaries and Coasts: Spatial and Temporal Intercomparisons,* Olsen & Olsen. Fredensborg, Denmark. 277-284 p.

Pope, K.L. & Willis, D.W. 1996. Seasonal influences on freshwater fsheries sampling data. *Rev. Fish. Sci.*, 4 (1): 57-73.

Potter, I.C.; Beckley L.E.; Whitfield, A.K. & Lenanton, R.C.J. 1990. Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and Southern Africa. *Environ. Biol. Fish.*, 28: 143-178.

Rakocinski, C.F.; Lyczkowski-Shultz, J.& Richardson, S.L. 1996. Ichthyoplankton Assemblage structure in Mississippi Sound as revealed by canonical correspondence analysis. *Estuar., Coast. Shelf Sci.*, 43: 237-257.

Rebelo, J.E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries*, 15 (3): 403-415.

Rebelo, J.E. & Pombo, L. 2001. *Os peixes da Ria de Aveiro – diversidade, ecologia e distribuição*. Câmara Municipal de Aveiro, Aveiro.

Rogers, S.G.; Targett, T.E.& Van Sant,S.B. 1984. Fish nursery use in Georgia salt-marsh estuaries: the influence of springtime freshwater conditions. *Trans. Am. Fish. Soc.,* 113: 595-606.

Rosecchi E. & Nouaze, Y. 1985. Comparaison de cinq indices alimentaires utilisés dans l'analyse des contenus stomacaux. *Ver. Trav. Inst. Pêches Mant.*, 49 (3, 4): 111-123.

Sokal, R.R. & Rohlf, F.J. 1995. *Biometry.* 3rd ed. W.H. Freeman & company, New York.

Ter Brack, C.J.F. 1986. Canonical correspondance analysis: A new eigenvector technique for multivariate direct gradient analysis. *Ecology*, 67: 1167-1179.

Van Leeuwen, P.I.; Rijnsdorp, A.D. & Vingerhoed, B. 1994. Variations in abundance and distribution of demersal fish species in the coastal zone of the Southeastern North Sea between 1980 and 1993. *Demersal Fish Committee*, 10: 1-19.

Whitehead, P.J.P.; Bauchot, M.L.; Hureau, J.C.; Nielsen, J. & Tortonese, E. 1986. *Fishes of the North-eastern Atlantic and the Mediterranean*. UNESCO, Paris.

Whitfield, A.K. 1996. Fishes and the environmental status of South African estuaries. *Fish. Manage. Ecol.*, 3: 45-57.

Wootton, R.J. 1990. *Ecology of teleosts fishes*. Chapman & Hall, London.

Zar, J.H. 1984. *Biostatistical Analysis*. 2nd ed. Prentice-Hall, Inc., New Jersey.

Ecology, Age and Growth of *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal

Pombo, L.; Elliott, M. & Rebelo, J.E. 2005.

Cybium, in press

Ecology, Age and Growth of *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal

Abstract

Atherina boyeri and *A. presbyter* show similar morphology and anatomy, which makes the species identification by conventional tools difficult. The ecological behaviour and biological features are markedly distinct in both species. In the Ria de Aveiro, a typical coastal estuarine lagoon, *A. boyeri* and *A. presbyter* are among the four most abundant species. Ecology, age and growth of both species were compared based on sampling carried out from November 1998 to November 1999 at nine sites covering all the lagoon area. *A. boyeri*, a resident species, occurred in different stages of the lifespan in the entire lagoon area. Juveniles occurred dispersedly in space, with no apparent abiotic preference. Older adults (2^{+}-3^{+}) occurred with high abundance at the edges of the lagoon, in winter, in deep regions with low temperature, salinity and transparency, and high dissolved oxygen and pH. The juveniles of marine juvenile migrant species, *A. presbyter*, were confined to deep regions of the lagoon edges, during autumn, with low temperature, salinity and transparency, high dissolved oxygen, and neutral pH. The adults occurred with high abundance near the sea, in mid-spring, in a narrow range of all abiotic parameters. The length frequency distribution, and the fish and otolith length-weight relationships were significantly different in both species. *A. boyeri* reached 11.6 cm in 3 years while *A. presbyter* reached 15.1 cm in 4 years. For the same length, *A. boyeri* (b= 3.4) was heavier than *A. presbyter* (b=3.1). The von Bertalanffy growth parameters for *A. boyeri* were L_8= 11.6 cm, k= 0.099 $year^{-1}$, and t_0=-3.797 years and for *A. presbyter* were L_8= 15.8 cm, k= 0.138 $year^{-1}$, and t_0= -2.501 years. *A. boyeri* and *A. presbyter* grew faster during the first year of life (66% and 43%, respectively). The observed and theoretical length and age were quite similar for both species and the values near those of different Atlantic and Mediterranean systems.

Keywords: ecological behaviour, life history, sympatric species, Atherinidae.

Introduction

The Atherinid fish species, big-scale sand smelt *Atherina boyeri* Risso, 1810 and sand smelt *A. presbyter* Cuvier, 1829, exhibit very similar morphology and anatomy. The taxonomic identification by the common morphometric characteristics, as head length, number of scales in longitudinal series, and number of vertebrae (Whitehead *et al*., 1986; Bauchot & Pras, 1987), is ambiguous and leads to some doubts. Bamber & Henderson (1985), inclusively, proposed the synonymy of *A. boyeri* with *A. presbyter*. However, recent studies approaching genetic and biological aspects have demonstrated differences between these two populations, consistent with the existence of two species (Creech, 1991, 1992). The species comprise distinct ecology behaviour and different geographical distribution. *A. boyeri* was described as a truly resident species, preferring littoral, estuaries, lagoons, and inshore areas forming land-locked populations where it spends its entire life (Elliott & Dewailly, 1995; Whitehead *et al.*, 1986). It is a very euryhaline species, from hyperhaline water (77 psu, in Corsica) to freshwater (Whitehead *et al*., 1986; Rosecchi & Crivelli, 1992, 1995; Leonardos & Sinis, 2000; Leonardos, 2001). The distribution area includes the Mediterranean and adjacent seas, the Black Sea and the Atlantic, from south of Spain to Morocco and Madeira. Isolated populations can be found on coasts of England and Netherlands (Whitehead *et al*., 1986; Rosecchi & Crivelli, 1992, 1995; Leonardos & Sinis, 2000; Leonardos 2001). *A. presbyter* was described as a marine juvenile migrant species, which uses estuaries and coastal lagoons primarily as a nursery ground. Much of its adult life is spent at sea, but it often returns seasonally to the estuary (Elliott & Dewailly, 1995). It occurs along the European and African coasts of the Atlantic Ocean, from the Kattegat (rare) and Scotland to Morocco, and around Madeira, Canaries and Cape Verde Islands. It is rare in the Mediterranean, found off Gibraltar, France and Tunisia (Whitehead *et al*., 1986; Lorenzo & Pajuelo, 1999; Pajuelo & Lorenzo, 2000).

The information about Atherinids is scarce and mainly focusing biological aspects such as age, growth and mortality (Fernandez-Delgado *et al*., 1988; Creech, 1992; Rosecchi & Crivelli, 1992; Rosecchi & Crivelli, 1995; Lorenzo & Pajuelo, 1999; Leonardos & Sinis, 2000; Pajuelo & Lorenzo, 2000; Leonardos,

2001), and morphological, morphometric, biochemical and genetic characteristics (Bembenuti, 1993; Trabelsi *et al*., 1994; Vasil'eva, 1994; Conglu *et al*., 1997; Focant *et al*., 1999; Klossa-Kilia *et al*., 2002; Trabelsi *et al*., 2002a and b).

Only *A. presbyter* was referred to the Portuguese coast, besides Ria de Aveiro, namely in Tagus estuary (Costa, 1986; Costa & Bruxelas, 1989), in Sado estuary (Cabral, 1999) and in Ria Formosa (Monteiro *et al*., 1987, Santos *et al*., 1996). *A. boyeri* was turned visible since 1992 in the Ria de Aveiro (Rebelo, 1992; Cruz & Rebelo, 2000; Rebelo & Pombo, 2001; Pombo & Rebelo, 2002; Pombo *et al*. 2002 a, b, c), so before that only *A. presbyter* was described to the lagoon (Nobre *et al*., 1915; Osório 1912; Arruda *et al*., 1988). Nowadays, both species are comprised in the four most abundant species of the lagoon.

This paper intends to distinguish two atherinids species (*A. boyeri* and *A. presbyter*) through their ecology, age and growth patterns, according to their occurrence in a typical estuarine coastal lagoon. These features intend to be a useful contribution to the identification of Atherinids besides the wide used traditional taxonomy.

Material and Methods

Study Area

The Ria de Aveiro (Fig. 1), on the west coast of Portugal is an estuarine lagoon with a maximum length of 45 km and maximum width of 11 km that delimit a total area between 42 km² (low tide) and 47 km² (high tide). The water volume is 70 million m^3, with an oceanic tidal contribution of between 25 million m^3 (neap-tides) to 90 million m^3 (higher spring tides). Four rivers (Vouga, Antuã, Caster and Boco) and uncounted streams flow between 3 m^3 s^{-1} and 60 m^3 s^{-1}, due to the influence of seasonal precipitations and run-off patterns. The depth varies between 0.6 m and 10.0 m. The mean substratum is silt, however sandy close to the lagoon's mouth and with immerses vegetation in the north extreme. The industrial and fishing ports, and the industries and population in the watershed are sources of three main pollution types: organic and chemical pollution, chemical pollution, and microbial contaminants (Barrosa, 1980; Lucas *et al*., 1986; Borrego *et al*., 1994).

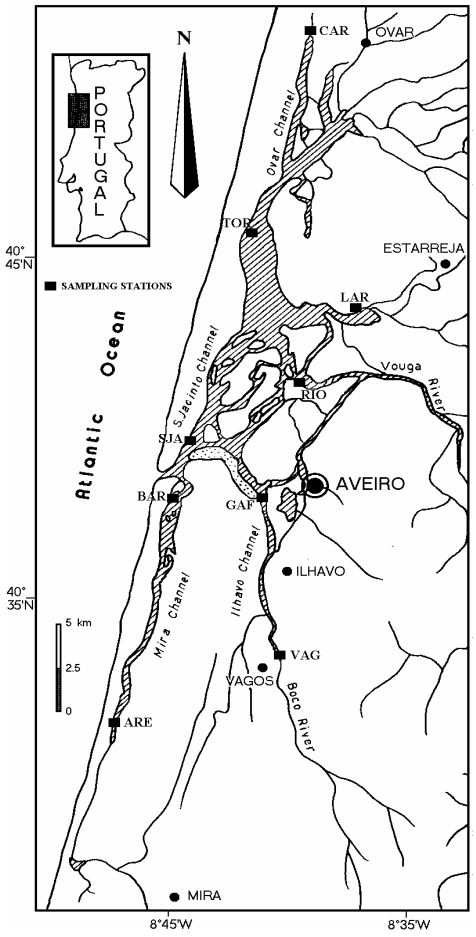

Fig.1 - Map of the Ria de Aveiro lagoon showing sampling stations.

The particular abiotic attributes of this system - shallowness, high turbidity, the nature of substract, temperature, salinity and oxygen - associated with its high biotic productivity, offer excellent conditions for colonisation by many species of fish, especially teleosts (Potter *et al*., 1990; Rebelo, 1992).

The Ria de Aveiro is economically important because of its fisheries, industry, agriculture, sea farming, tourism and, more recently, aquaculture. With a good communication with the sea that guarantees seasonally the fish recruitment, the lagoon is an area of considerable fish exploitation (commercial and recreational). Previous fish studies in the Ria de Aveiro (Osório, 1912; Nobre *et al*., 1915; Arruda *et al*., 1988; Rebelo, 1992; Pombo & Rebelo, 2002; Rebelo & Pombo, 2001; Pombo *et al*, 2002 b) contributed to the knowledge about the dynamics and the evolution of the fish populations inside the lagoon and its relationship with the adjacent ocean.

Field Sampling

Fish were collected monthly, from November 1998 to November 1999, at nine selected sites (Fig. 1): near the mouth of the lagoon (BAR, GAF and SJA); at the edges of the main channels (ARE, CAR and VAG); in the main freshwater area, highly organically enriched (RIO); in the region of higher levels of industrial pollution (LAR), and approximately in the middle of the longest channel (TOR).

At each site and each month, 3 non-overlapping replicate samples were taken at low spring tide, over the five days of the new moon. The total area enclosed by the gear was approximately 193 m^2 in each trawl. A “chincha” or

traditional beach-seine net (Nobre *et al*., 1915) was used to sample fish. The "chincha" gear used was almost rectangular in shape and composed by a central bag (a 'cod-end', 295 cm of length and 145 cm of wide), two lateral wings (12 m of length each, the width decreasing along the net, reaching 50 cm at the edge), two ropes (6.1 m each), floating buoys at the top and ceramic weights at the bottom of the net. The stretched mesh sizes in the gear were 19 mm at the wings, 17 mm at the cod mouth, 16 mm at the cod sleeve, and 10 mm at the cod-end. The end of the net was fixed to the margin and the remainder was trawled in a semi-circle thus retaining within the cod-end all the fish from the area. The net efficiency is estimated at 90% (Elliott & Hemingway 2002).

Abiotic parameters (temperature and dissolved oxygen) were recorded with an oxygen meter (CONSORT Z621), the salinity was recorded with a refractometer (ATAGO), pH was recorded with a pH meter (WTW pH 330/SET-2), and the percentage of water transparency was estimated based on turbidity and Secchi depth, according to Yáñez-Arancibia (1983).

Fish and Otolith Use

Fish were preserved by freezing. At the laboratory, specimens were identified using to the taxonomic keys of Whitehead *et al*. (1986) and Bauchot & Pras (1987). The species identification was made by at least two investigators and only coincided results were considered to minimise possible errors of identification.

Fish were measured to the nearest 0.1 cm (total length, L), and weighed to the nearest 0.1 g (total fresh weight, W). The total abundance of each species in terms of fish numbers captured in the three replicates was recorded in each site each month.

Otoliths and scales were removed from fish obtained in aleatory sub-samples and stored dry in properly labelled envelopes. The scales were removed from the base of the pectoral fin in the longitudinal line. Otoliths were measured, from the anterior tip to the posterior projection, to the nearest 0.1 mm, and weighed, to the nearest 0.1 mg. Right otoliths were examined, except in abnormal cases (i.e. broken), where the left was examined, under reflected light with a stereo microscope (OLYMPUS SZ60-PT) having a micrometer eyepiece. The number of

opaque zones (winter rings, appearing bright under reflected light) and the presence of a marginal translucent zone (summer rings, appearing dark under reflected light) were registered. Otoliths were compared to scale ageing readings made by two investigators and only coincided readings were considered to minimise observation errors.

Data Analysis

The threshold values of abiotic parameters (temperature, salinity, dissolved oxygen, pH, depth and transparency) were opposed with space abundances of *A. boyeri* and *A. presbyter*. The log-transforming abundance data were used to minimize large differences recorded.

The length distributions of both species were compared by Kolmogorov-Smirnov (K-S) two-sample test (Sokal & Rohlf, 1995; Zar, 2000).

The fish length-weight relationship was calculated using all individuals sampled, following the Gulland's equation (Gulland, 1969): $W = a\ L^{b}$, where W is the total body weight (g), L is the total length (cm), and a and b are the regression coefficients. The same equation was adopted for otoliths length-weight relationship. The comparison of slopes of fish length-weight and the otolith length-weight relationships was carried out by using the Student's t test with log-transforming data: $t = \frac{b_1 - b_2}{S_{b_1 - b_2}}$, where b_1 and b_2 are the regression coefficients and $S_{b1\text{-}b2}$ is the standard error of the difference between regression coefficients (Zar, 2000).

The difference of the otolith age groups was composed for each species by Kruskal-Wallis (K-W) one-way analysis.

Age growth was expressed in terms of the von Bertalanffy equation (von Bertalanffy, 1938): $L_t = L_\infty \left[1 - e^{-k(t - t_0)}\right]$, where L_t is the fish length at age t, L_8 is the maximum asymptotic length, k is the growth curvature parameter, and t_0 is the computed age where the fish has no growth both in length and weight. The growth parameters were estimated by the software ELEFAN I, included in FISAT and developed by Pauly and David (Pauly, 1987).

Results

Abiotic Parameters

The Ria de Aveiro is influenced by a maritime temperate climate. The seasonality of the air temperature and rainfall is well marked. The warm period occurred during summer (from June to September) and the cold period occurred during the late autumn and winter (from December to February). The water temperature ranged from 7.6ºC, at VAG, in winter, to 26.7ºC, at CAR, in summer. The salinity ranged from freshwater (0.0 psu), at RIO, in winter, to marine water (35.0 psu) at the mouth of the lagoon and at TOR, in summer. The dissolved oxygen ranged from 4.8 mg l^{1}, in autumn, at BAR, to 13.2 mg l^{1}, at CAR and VAG, both in winter. The pH ranged from 6.9, at LAR, in autumn, to 8.6, at ARE, in winter. The depth ranged from 0.6 m, at ARE, in summer, to 5.4 m, at RIO, in winter, and the opposite occurred with the transparency, which ranged from 4.4%, at VAG, in summer, to 100.0%, at TOR, in winter.

Abundance (in terms of Fish Numbers) and Abiotic Environment

In spite of a general distribution in all the lagoon area, the two species showed different spatial preferences, associated to particular abiotic environment. *A. boyeri* occurred with high abundance (more than 180 specimens – 7% of total abundance) during winter at the edges of the lagoon (CAR and VAG), where the water turnover was lower. The highest abundance was recorded in periods where the abiotic parameters – temperature (7.6-12.0 ºC), salinity (10.0- 21.0 psu) and transparency (13.7-21.7%) – were lower than the observed for *A. presbyter* occurrence. *A. presbyter* occurred mainly (more than 40% of total abundance) in areas with high levels of chemical and oil pollution (LAR and VAG) and near the lagoon mouth (GAF). The highest abundance was recorded in periods with relative high values of the temperature (11.2 – 13.5ºC), salinity (28.0 – 32.0 psu) and transparency (20.7 – 28.6%).

The dissolved oxygen, pH and depth parameters appeared not contributing to the distinction of the two populations. *A. boyeri* and *A. presbyter* occurred with high abundance in periods with similar values of dissolved oxygen (4.8 - 9.8 mg l^{1}

and 5.4 – 8.3 mg l^{-1}, respectively), pH (7.2 – 8.3 and 7.3 – 8.0, respectively) and depth (3.4 – 4.4 m and 3.2 – 4.5 m, respectively).

Occurrence per Age

The lifespan migration patterns inside the lagoon were noticeably different for *A. boyeri* and *A. presbyter*. Both juveniles (0^+) and older adults (3^+) of *A. boyeri* (Table 1) occurred close the lagoon mouth (BAR and GAF) and throughout the main channel (TOR). However, the highest abundance was recorded at the north (CAR) and south (VAG) edges of the lagoon, in winter, with specimens mainly belonging to the 2^+-age class.

Table 1 - Abundance (number of fish, length (cm TL)), weight and age ranges of *A. boyeri* and *A. presbyter* per sampling site (SS) and in all the Ria de Aveiro lagoon (Total).

A. boyeri

SS	ARE	BAR	CAR	GAF	LAR	RIO	SJA	TOR	VAG	Total
Abundance	101	42	1093	158	90	73	93	60	793	2503
Length (cm)	4.2 - 9.7	1.56 - 9.00	4.3 - 9.6	2.7 - 11.1	3.4 - 10.6	4.1 - 9.2	4.4 - 11.6	2.9 - 7.7	3.9 - 10.5	1.6 - 11.6
Weight (g)	0.4 - 7.3	0.1 - 4.2	0.5 - 5.6	0.1 - 9.1	0.1 - 8.8	0.5 - 5.9	0.4 - 11.5	0.1 - 2.6	0.2 - 8.4	0.1 - 11.5
Age (years)	0+ - 3+	0+ - 3+	0+ - 3+	0+ - 3+	0+ - 3+	0+ - 3+	0+ - 3+	0+ - 3+	0+ - 3+	0+ - 3+

A. presbyter

SS	ARE	BAR	CAR	GAF	LAR	RIO	SJA	TOR	VAG	Total
Abundance	12	92	46	535	133	16	96	81	158	1169
Length (cm)	5.00 - 8.8	6.1 - 13.3	7.4 - 13.5	5.2 - 13.4	6.1 - 15.1	6.8 - 12.1	5.1 - 12.6	4.1 - 13.6	5.6 - 13.6	4.1 - 15.1
Weight (g)	0.8 - 4.6	1.3 - 16.2	2.6 - 19.0	0.8 - 17.8	1.2 - 27.9	1.8 - 13.4	0.8 - 13.4	0.4 - 17.2	1.1 - 17.9	0.4 - 27.9
Age (years)	0+ - 1+	0+ - 3+	1+ - 3+	0+ - 3+	0+ - 4+	0+ - 2+	0+ - 2+	0+ - 3+	0+ - 3+	0+ - 4+

Younger specimens (0^+ - 1^+) of *A. presbyter* (Table 1) occurred mainly at the south edge of the lagoon (VAG). Older fish (2^+ - 3^+) occurred more abundantly close to the mouth of the lagoon (BAR and GAF), during the reproductive migration in mid-spring. High abundance during all the year was recorded in a particular site (GAF) near the sea.

Length Frequency Distribution

The length composition (Fig. 2) significantly varied between the two species (K-S test: d max = 0.4, $p<0.001$). For *A. boyeri* the minimum and maximum lengths were 1.6 cm and 11.6 cm, respectively, while for *A. presbyter* were 4.1 cm and

15.1 cm, respectively. The most abundant length classes were 6.5-8.5 cm, for *A. boyeri*, and 10.5-12.5 cm, for *A. presbyter*.

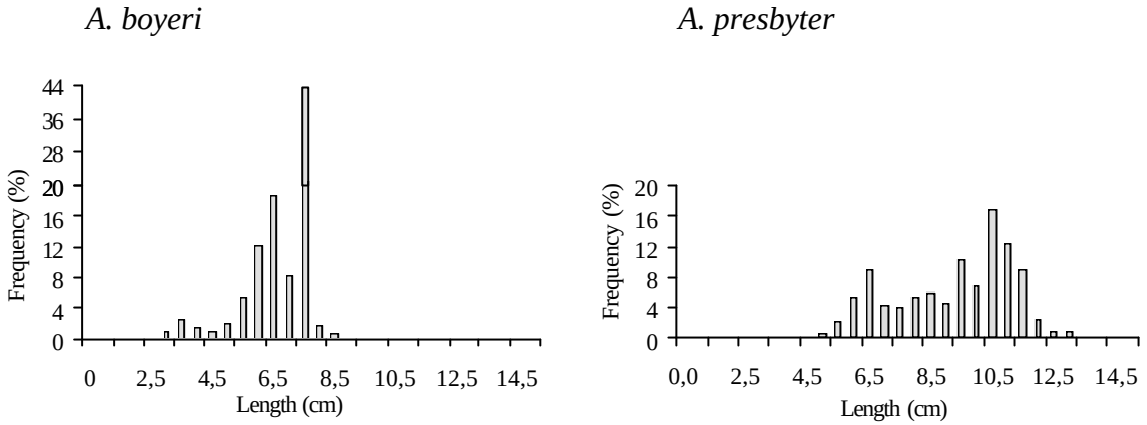

Fig. 2 - Length frequency (cm TL) distribution of *A. boyeri* (N= 2503) and *A. presbyter* (N= 1169).

Length-Weight Relationship

Fish length-weight relationship, an expression of growth, was established separately to the two species. Both equations showed that the weight grew allometrically with the length; the *b* values (b>3) showed that species grew faster in weight than in length (Tesch, 1971). For the same length, *A. boyeri* (b= 3.4) became heavier than *A. presbyter* (b= 3.1). The comparative analysis of the regressions revealed statistically different slopes (t= 28.02, p<0.001).

Otoliths Length-Weight Relationship

The Gulland's growth equation to fish length and weight revealed to be fitted to the otoliths growth. *A. boyeri*'s otoliths grew faster in length than in weight (b= 2.9). The opposite occurred for *A. presbyter* (b= 3.1). The comparative analysis of the otolith regressions revealed statistically different slopes (t= 6.15, p<0.001).

The otolith growth followed the fish growth. The smallest fish (3.4 cm for *A. boyeri* and 4.6 cm for *A. presbyter*) was set to match with the smallest otolith length (1.3 and 1.8 mm respectively), and the longest fish (11.6 cm for *A. boyeri* and 15.1 cm for *A. presbyter*) was set to match with the longest otolith length (4.3 and 5.4 mm respectively).

The relationship between fish length and otolith length was similar in both species (*t*= -3.760, p>0.05), i.e., the otolith length attends the fish length at the same proportions for both species.

Age and Growth

Intending to compare the length-age growth, the otoliths lengths were divided into one-year age groups. In both species the otoliths' lengths were statistically different between age groups (H= 120.62, p<0.001 for *A. boyeri* and H= 306.30, p<0.001 for *A. presbyter*).

The mean incremental growth per age group was higher for *A. boyeri*, between 0.6 cm and 1.4 cm, than for *A. presbyter*, between 1.8 cm and 2.6 cm (Fig. 3). The proportion of growth was calculated for each age group. The first year of life growth for *A. boyeri* and *A. presbyter* (66% and 43%, respectively) was remarkably faster than the consequent age groups.

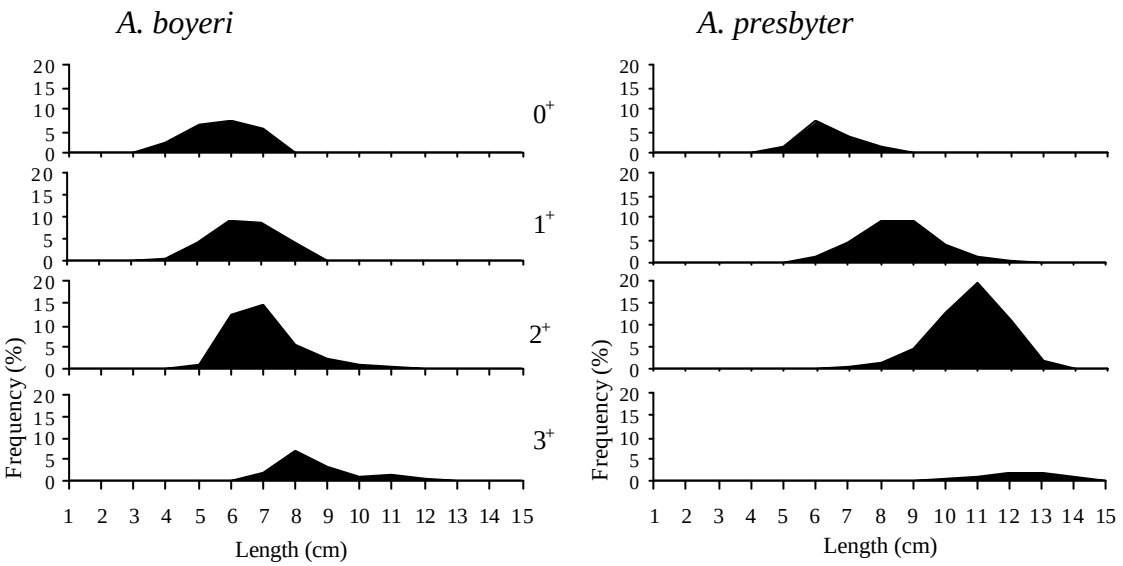

Fig. 3 - Length and age frequency distribution of *A. boyeri* (N= 350) and *A. presbyter* (N= 477).

In both species, the 2^+ age group was found to be the most abundant, followed by 1^+, 0^+ and 3^+ age groups. The 4^+ age group was just found for A. presbyter, but only in a unique specimen, though it is not represented in figure 3.

The von Bertalanffy growth equation was established for *A. boyeri* and *A. presbyter* (Table 2). In both species, the theoretical lengths for *A. boyeri*, 11.6 cm, and for *A. presbyter*, 15.8 cm, were realistic and agreed to the largest specimen caught during this study, 11.6 cm and 15.1 cm, respectively. Theoretical length values were compared with the fish length collected from nature (Table 3) and found to coincide.

Table 2 - Comparison of von Bertalanffy parameters established for *A. boyeri* (N=350) and *A. presbyter* (N= 477).

Species	L_8 (cm)	k (year $^{-1}$)	t_0 (years)
A. boyeri	11.6	0.099	-3.797
A. presbyter	15.8	0.138	-2.501

Table 3 - Comparison of observed length values (cm TL) of the samples and theoretical calculated length values, according to age groups of *A. boyeri* and *A. presbyter*.

Age groups	*A. boyeri*				*A. presbyter*			
	N	Observed	Theoretical	% Growth	N	Observed	Theoretical	% Growth
0^+	79	5.6	5.5	65.5	71	6.5	6.6	43.1
1^+	90	6.2	6.6	10.3	140	8.5	8.7	13.0
2^+	131	7.1	7.6	7.4	238	10.7	10.5	15.0
3^+	50	8.6	8.5	16.8	27	12.5	12.1	11.7
4^+	_	_	_	_	1	15.1	13.4	17.2

Discussion

The ecotone Ria de Aveiro is strongly influenced by the weather, showing a large range of abiotic parameters. The constant influences of marine and freshwaters, and the seasonal changes in temperature, rainfall, and wind, together produce high summer and low winter values of water temperature and salinity, with the reverse for oxygen. The pH is influenced by pollution, and transparency varies according to depth (Rebelo, 1992; Anon., 1994; Borrego *et al*., 1994). The complexity of the system allows the occurrence of a high diverse fish community, grouped in distinct ecological guilds. The sedentary species, including *A. boyeri*,

and the marine juvenile migrant species, including *A. presbyter*, comprise the most representative lagoon guilds (Rebelo, 1992; Elliott & Dewailly, 1995; Pombo *et al*., 2002b).

A. boyeri and *A. presbyter*, in spite of being always present in space and time, showed separate abiotic preferences. *A. boyeri* mainly occurred at lower abiotic limits than *A. presbyter* for temperature, salinity and transparency.

Both species showed separate ecological behaviours of abundance and migration inside the lagoon, associated to the abiotic environment. *A. boyeri* was confined to the edges of the lagoon, during the winter, for spawning (Fernández-Delgado *et al*., 1988; Rosecchi & Crivelli, 1992). Individuals of 7-8 cm of total length (2-3 years) appeared with a large abundance, at deep regions with low temperature, salinity and transparency, and high dissolved oxygen and pH, mostly at the north and south edges of the lagoon. In the remaining time of the year, specimens occurred dispersedly in space, with no apparent abiotic preference.

In general, *A. presbyter* occurred with almost twice-lower abundance than *A. boyeri*. The species showed an evident selective spatial distribution with the age. Juveniles occurred with high abundance at deep regions of the lagoon edges, during autumn, with low temperature, salinity and transparency, high dissolved oxygen, and neutral pH. The high vegetation and productivity of these regions provided high food sources and refuges to this critical lifespan period. In the second year of life, fish began to migrate, to the entrance area when they were getting maturity for spawning (Pajuelo & Lorenzo, 2000). With the increasing size (10-15 cm) and age (2-3 years) adult fish occurrence was restricted, with high abundance, to a particular area close to the sea (Rebelo, 1992; Pombo & Rebelo, 2002; Cruz & Rebelo, 2000; Pombo *et al*., 2002c). That high adult abundance occurred associated to marine levels of salinity, high values of temperature, depth and transparency, neutral pH and low dissolved oxygen.

Biological features, as length, weight, growth and age were distinctive in both species. The length composition was markedly different. *A. boyeri* was smaller but heavier than *A. presbyter*. The growth in length was generally slow and lower for *A. boyeri* than for *A. presbyter*, except during the juvenile period. Atherinids, in general, experienced a fast early growth rate through the first year of age

(Fernandez-Delgado *et al.*, 1988; Creech, 1992; Leonardos & Sinis, 2000), after which the annual growth rate drops rapidly, resulting of less energy available for somatic growth associated to sexual maturity (Pajuelo & Lorenzo, 2000). In the first year of life, *A. boyeri* reached approximately two third of the maximum length. The same result was obtained to Greek Mediterranean lagoons (Leonardos & Sinis, 2000). *A. presbyter* reached less than half of maximum length in the first year of life, opposing to 60% registered in the Canary Islands (Lorenzo & Pajuelo, 1999) (Table 4). The abiotic and biotic latitude differences, especially the temperature and productivity, may influence the low growth in Aveiro lagoon.

Along their lifespan, *A. boyeri* and *A. presbyter* depend on high productive systems, such as coastal lagoons. The length-weight relationship denoted high energetic storage for both species, however, significantly higher for the resident species, *A. boyeri*, than for the marine juvenile migrant species, *A. presbyter*. Coastal lagoons and lakes provide higher productivity than rivers. Fish occurring in these systems exhibit high energetic storage.

Table 4 - Maximum age, number of specimens sampled (N), length-weight relationship parameters (a, b) and von Bertalanffy parameters (L8, K, t_0) of *Atherina boyeri* and *A. presbyter* in different systems of Atlantic and Mediterranean (adapted from Leonardos & Sinis, 2000).

Authors	Study area	Maximum age (years)	*N*	*a*	*b*	*L?* (cm)	*K* ($year^{-1}$)	t_0 (years)
			Atherina boyeri					
Fernandez-Delgado *et al*., 1988	Guadalquivir River, Spain	2	2510	$7.0x\ 10^{-3}$	2.98	_	_	_
Creech, 1992	Aberthaw Lagoon S. Wales	2	329	$3.5x10^{-6}$	3.27	9.2	_	_
Leonardos & Sinis, 2000	Mesolongi, Etolikon W. Greece	3	4269	$4.2x10^{-3}$	3.15	11.6	0.240	-1.270
Leonardos, 2001	Trichonis Lake W. Greece	4	572	$3.8x10^{-6}$	3.45	12.3	0.374	0.018
Present study	Ria de Aveiro, Portugal	3	2503	$3.3x10^{-3}$	3.35	11.6	0.099	-3.797
			Atherina presbyter					
Pajuelo & Lorenzo, 2000	Atlantic Canary Islands	3	1028	$6.1x10^{-3}$	3.08	12.2	0.790	0.210
Present study	Ria de Aveiro, Portugal	4	1169	$5.5x10^{-3}$	3.09	15.8	0.138	-2.501

For *A. boyeri* the *b* value was very close to the values established in the Atlantic Aberthaw lagoon (Creech, 1992), in the Mediterranean Mesolongi and Etolikon lagoons (Leonardos & Sinis, 2000) and in the Mediterranean lake Trichonis (Leonardos, 2001). In contrast, in Guadalquivir river, the *b* value was the lowest (Table 4). The *A. presbyter b* value was very similar to the Atlantic Canary

Islands (Pajuelo & Lorenzo, 2000), in the south limit of the species distribution (Table 4).

The biometric otolith analysis showed that the otoliths growth followed the fish growth independently of the species or the maximum length that each species can reach. However, as well as for the fish length/weight, the significantly difference between *A. boyeri* and *A. presbyter* otolith length/weight relationship contribute to distinguish the two species. Most growth studies on sand smelts have used otoliths or statistical methods, rarely scales. In this study, the coincided results obtained with the two methods together (otoliths and scales) and made by two people was used to minimise errors of age recordings in order to produce more trustworthy results, although not infallible.

The age and length composition of both species was quite different. The estimated L_8 (11.6 cm for *A. boyeri* and 15.8 cm for *A. presbyter*) was in close agreement with the maximum length recorded (L_{max}= 11.6 cm and L_{max}= 15.1 cm, respectively). The theoretical maximum length values were reasonably higher than the maximum sampled size. In *A. boyeri*, L_8 was very similar to the Greek Mediterranean lagoons (Leonardos & Sinis, 2000) and deeply higher than in Wales (Aberthaw lagoon) (Creech, 1992). In contrast, the Mediterranean lake system (Leonardos *et al*., 1993) exhibited a maximum value of L_8 (Table 4). For *A. presbyter*, L_8 was higher than in the Atlantic Canary Islands (Pajuelo & Lorenzo, 2000) (Table 4).

A. boyeri and *A. presbyter* are sympatric species that might occur at the same space and in the same time. Both species showed similar macroscopic shape, leading to a generalised difficulty on species identification through the conventional taxonomic identification. Furthermore, on the basis of morphoanatomical parameters, the sand smelt species is viewed as a highly polymorphic complex (Trabelsi *et al*., 2002a and b). Thus further studies on biometric, biochemical and genetic investigations in the lagoon will be needed to deal with this problem with more severity. Using the tools that were available for this study, and with conscious of some limitations of the methods, and as a preliminary work, this study allowed to distinct ecological behaviour and biological characteristics between species. The abundance and distribution per space and

time by length and age, the abiotic preference during the lifespan, the fish and otolith length-weight relationships and the age and growth parameters were markedly distinct in both species. Thus, some of these ecological and biological parameters can be generally useful as accessory tools in the taxonomic identification of the Atherinids species.

Acknowledgements

We would like to thank the University of Aveiro, the Foundation for Science and Technology and the European Social Fund for their financial support of this research. The authors are also very grateful to all the students who helped in the field and laboratory work.

References

Anonymous, 1994. *Solução integrada de colecta, tratamento e destino final dos efluentes líquidos. Parte 4. Estudo de impacte ambiental. Resumo não técnico AMRIA*, Volume 2. AMRIA, Aveiro.

Arruda, L.M.; Andrade, J.P. & Cunha, M.M. 1988. Abundance, diversity and community structure of the fish population in the Ria de Aveiro (Portugal). *Oceanol. Acta*, 11 (3): 235-240.

Bamber, R.N. & Henderson, P.A. 1985. Morphological variation in British atherinids, and the status of *Atherina presbyter* Cuvier (Pisces: Atherinidae). *Biol. J. Linn. Soc.*, 25: 61-76.

Barrosa, J.O. 1980. A Ria de Aveiro e a sua influência na economia da região. *Recursos hídricos*, 1 (3): 83-96.

Bauchot, M.L. & Pras, A. 1987. *Guía de los peces de mar de España y de Europa*. Ediciones Omega, Barcelona.

Bembenuti, M.A. 1993. Redescription of Odontesthes argentinensis (Valenciennes) Pisces: Atherinidae, from the Rio Grande do Sul Coast. *Atlantica Rio grande*, 15: 17-35.

Borrego, C.; Cruz, M.M. & Gonçalves, P. 1994. *Estudo de avaliação da vulnerabilidade da capacidade de recepção das águas costeiras em Portugal. Relatório R 3.2. Meios receptores e suas características: (Be 1): Ria de Aveiro, Pateira de Fermentelos e Barrinha de Mira*. Projecto 13/94. IDAD, Aveiro.

Cabral, H.N. 1999. *Ictiofauna do Estuário do Sado. Relatório Científico Técnico*. No. 47. Instituto de Investigação das Pescas e do Mar, Lisboa.

Conglu, L.; Bertelli, G. & Colombo, G. 1997. Genetic differences among populations of *Atherina boyeri*, Risso 1810, of Italian coastal lagoons, observed with the method of RAPD (Random Amplified Polymorphic DNA). *Biol. Mar. Mediterr.*, 4 (1): 478-480.

Costa, M.J. & Bruxelas, A. 1989. The structure of fish communities in the Tagus Estuary, Portugal, and its role as a nursery for commercial fish species. *Sci. Mar.*, 53 (2-3): 561-566.

Costa, M.J. 1986. Les poissons de l'Estuaire du Tage. *Cybium*, 10 (1): 57-75.

Creech, S. 1991. An electrophoretic investigation of populations of *Atherina boyeri* Risso, 1810 and *A. presbyter* Cuvier, 1829 (Teleostei: Atherinidae): genetic evidence in support of the two species. *J. Fish Biol.*, 39: 807-816.

Creech, S. 1992. A multivariate morphometric investigation of *Atherina boyeri* Risso, 1810 and *A. presbyter* Cuvier, 1829 (Teleostei: Atherinidae): morphometric evidence in support of the two species. *J. Fish Biol.*, 41: 341-353.

Cruz, R. & Rebelo, J.E. 2000. Growth data in fish of the Ria de Aveiro. *Rev. Biol. (Lisboa)*, 18: 41-47.

Elliott, M. & Dewailly, F. 1995. The structure and components of European estuarine fish assemblages. *Neth. J. Aquat. Ecol.*, 29 (3-4): 397-417.

Elliott, M. & Hemingway, K. L. (Eds.). 2002. *Fishes in Estuaries*. Blackwell Science, Oxford.

Fernandez-Delgado, C.J.A.; Hernando, M.H. & Bellido, M. 1988. Life history patterns of the sand smelt *Atherina boyeri* Risso 1810 in the estuary of the Guadalquivir River, Spain. *Estuar. Coast. Shelf Sci.*, 27: 697-706.

Focant, B.; Rosecchi, E.& Crivelli, A.J. 1999. Attempt at biochemical characterization of sand smelt *Atherina boyeri* Risso, 18110 (Pisces, Atherinidae) populations from the Camargue (Rhône delta, France). *Comp. Biochem. Physiol.*, 122: 261-267.

Gulland, J.A. 1969. Manual of methods for fish stock assessment, Part 1. Fish population analysis. *FAO Man. Fish Science*, 4: 1-154.

Klossa-Kilia, E.; Prassa, M.; Papasotiropoulos, V.; Alahiotis, S. & Kilias, G. 2002. Mitochondrial DNA diversity in *Atherina boyeri* populations as determined by RFLP analysis of three mtDNA segments.*Heredity,* 89: 363-370.

Leonardos, I. & Sinis, A. 2000. Age, growth and mortality of *Atherina boyeri* Risso, 1810 (Pisces: Atherinidae) in the Mesolongi and Etolikon lagoons (W. Greece). *Fish. Res.*, 45: 81-91.

Leonardos, I.D. 2001. Ecology and exploitation pattern of a landlocked population of sand smelt, *Atherina boyeri* (Risso 1810), in Trichonis Lake (western Greece). *J. Appl. Ichthyol.*, 17: 1-5.

Lorenzo, J.M. &. Pajuelo, J.G. 1999. Age and growth of the Sand Smelt *Atherina (Hepsetia) presbyter* Cuvier, 1829 in the Canary Islands (central-east Atlantic). *Fish. Res.*, 41: 177-182.

Lucas, M.F.; Caldeira, M.T.; Hall, A.; Duarte, A.C. & Lima, C. 1986. Distribution of mercury in the sediments and fishes of the lagoon of Aveiro, Portugal. *Water Sci. Technol.*, 18: 141-148.

Monteiro, C. ; Lam Hoai, T. & Lasserre, G. 1987. Distribution chronologique des poissons dans deux sites de la laguna Ria Formosa (Portugal). *Oceanol. Acta*, 10 (3): 359-371.

Nobre, A.; Afreixo, J.& Macedo, J. 1915. *A Ria de Aveiro, relatório oficial do regulamento da Ria de 28 de Dezembro de 1912*. Imprensa Nacional, Lisboa.

Osório, B. 1912. Pescas e peixes. Uma nota relativa à pesca e aos peixes da Ria de Aveiro. *Bol. Soc. Geogr. Lisboa*, 30 (4-5): 216-224.

Pajuelo, J.G. & Lorenzo, J.M. 2000. Biology of sand smelt, *Atherina presbyter* (Teleostei: Atherinidae), off the Canary Islands (central-east Atlantic). *Environ. Biol. Fish.*, 59: 91-97.

Pauly, D. 1987. A review of the ELEFAN system for analysis of length-frequency data in fish and aquatics invertebrates. In: Pauly, D. & Morgan, G.R. (Eds.), *Length-based methods in fisheries research.* Institute for Science Research. Manila, Philippines & Kuwait. 7-14p.

Pombo, L. & Rebelo, J.E. 2002. Spatial and temporal organisation of a coastal lagoon fish community, Ria de Aveiro, Portugal. *Cybium*, 26 (3): 185-196.

Pombo, L.; Dias, C.& Rebelo, J.E. 2002 a. Diet comparison between *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal. *Rev. Biol. (Lisboa)*, 20: 59-72.

Pombo, L.; Lopes, C. & Rebelo, J.E. 2002 c. A comparison study on the age and growth of *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal. *Rev. Biol. (Lisboa)*, 20: 47-58.

Pombo, L.; Elliott, M.& Rebelo, J.E. 2002 b. Changes in the fish fauna of the Ria de Aveiro estuarine lagoon (Portugal) during the twentieth century. *J. Fish Biol., 61* (Supplement A): 167-181.

Potter, I.C.; Beckley, L.E.; Whitfield, A.K. & Lenanton, R.C.J. 1990. Comparisons between the roles played by estuaries in the life cycles of fishes in temperate Western Australia and Southern Africa. *Environ. Biol. Fish.*, 28: 143-178.

Rebelo, J.E. & Pombo, L. 2001. *Os peixes da Ria de Aveiro – diversidade, ecologia e distribuição*. Câmara Municipal de Aveiro, Aveiro.

Rebelo, J.E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries*, 15 (3): 403-415.

Rosecchi, E. & Crivelli, A.J. 1992. Study of a sand smelt (*Atherina boyeri* Risso 1810) population reproducing in fresh water. *Ecol. Freshwat. Fish*, 1 (2): 77-85.

Rosecchi, E. & Crivelli, A.J. 1995. Sand smelt (*Atherina boyeri*) migration within the waters system of the Camargue, southern France. *Hydrobiologia*, 300/301: 289-298.

Santos, M. ; Monteiro, C. & Lasserre, G. 1996. Faune ichthyologique comparée de deux récifs artificiels du littoral de la Ria Formosa (lagune Portugal): résultats préliminaires. *Oceanol. Acta*, 19 (1): 89-97.

Sokal, R.R. & Rohlf, F.J. 1995. *Biometry*. 3rd ed. W.H. Freeman and Company, New York.

Tesch, F.W. 1971. *Age and growth in Methods for Assessment of Fish Production in Fresh Waters. IBP Handbook n. 3.* 2nd ed. W.E. Ricker Edition, Oxford and Edinburgh.

Trabelsi, M.; Gilles, A.; Fleury, C.; Mâamouri, F.; Quignard, J.-P. & Faure, E. 2002 b. Atherina punctata and Atherina lagunae (Pisces, Atherinidae), new species in the Mediterranean Sea. 2. Molecular investigations of three Atherinid species. *R.C. Biologies*, 1: 1-10.

Trabelsi, M.; Faure, E.; Quignard, J.-P.; Boussaïd, M.; Focant, B. & Mâamouri, F. 2002 a. *Atherina punctata* and *Atherina lagunae* (Pisces, Atherinidae), new species in the Mediterranean Sea. 1. Biometric investigations of three Atherinid species. *R.C. Biologies*, 1:1-9.

Trabelsi, M.; Quignard, J.-P. & Kartas, F.1994. *Atherina boyeri*: first mention of two sympatric populations in the Mediterranean Sea. *Cybium*, 18 (4): 457-459.

Vasil'eva, E.D. 1994. Skull morphology in atherines from the Black, Azov and Caspian Seas and some systematic problems of the genus *Atherina* (Atherinidae). *Vopr. Ikhtiol*., 34 (5): 611-621.

Von Bertalanffy, L. 1938. A quantitative theory of organic growth (inquires on growth laws II). *Hu. Biol*., 10: 181-213.

Whitehead, P.J.P.; Bauchot, M.-L.; Hureau, J.-C.; Nielsen, J. & Tortonese, E. 1986. *Fishes of the North-eastern Atlantic and the Mediterranean.* 3 volumes. UNESCO, U.K.

Yáñez-Arancibia, D.F. 1983. Environmental behavior of Terminos Lagoon ecological system, Campeche, México. *Anais del Instituto de Ciencias del Mar y Limnologia de la Universidad Nacional Autónoma de México,* 10 (1): 137-176.

Zar, J.H. 2000. *Biostatistical Analysis.* 4th ed. Prentice-Hall Inc., New Jersey.

Feeding Habits of Two Sympatric Species, *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829, in the Ria de Aveiro, Portugal

Pombo, L.; Dias, C.; Elliott, M. & Rebelo, J.E.

Journal of Applied Ichthyology, submitted

Feeding habits of two sympatric species, *Atherina boyeri* RISSO, 1810 and *Atherina presbyter* CUVIER, 1829 in the Ria de Aveiro, Portugal

Abstract

Feeding habits of *Atherina boyeri and Atherina presbyter* in an estuarine lagoon in the west coast of Portugal were studied over 13 months (November 1998/99) and covering all the lagoon area. A total of 346 stomachs of *A. boyeri* and 493 stomachs of *A. presbyter* were analysed. The new approach of modified Costello method was used to characterise the diets of fish. The species are found to be microcarnivorous (Garcia, 1994; Azevedo, 1995), whose diet is based on small crustaceans, and euryphagic (Nikolsky, 1963; Mirto *et al*., 1994), as they feed on a large variety of prey. This generalist strategy affords a degree of opportunism in the feeding of sand-smelts (Turnpenny *et al*., 1981). Diet breadth was higher for *A. presbyter* leading to a more mixed feeding strategy comparing to *A. boyeri*. The diet overlap between both species was only evident on older individuals. The general strategy of occupation of *A. boyeri* is based on high densities of occurrence and spatial preference for certain environments, this strategy could reduce interspecific competition by space exclusion of the other species (Moreno & Castro, 1995). The use of coastal ecosystem during different periods of time is a strategy (Moreno & Castro, 1995) that only *A. presbyter* can use that reduces competition between species for food resources. The combination of different strategies of each species gives a wider spectrum of the possibilities of exploitation of the coastal ecosystem food resource, thus reducing interspecific competition.

Keywords: feeding habits, sympatric species, Atherinidae, Ria de Aveiro, Portugal.

Introduction

The family Atherinidae is one of the most abundant fish families of the Ria de Aveiro (Rebelo, 1992; Pombo & Rebelo, 2000, 2002; Pombo *et al*., 2002). In this lagoon only the single genus *Atherina* was found, commonly referred as sand

smelt. The big-scale sand smelt, *Atherina boyeri* Risso, 1810, and the sand smelt, *Atherina presbyter* Cuvier, 1829, are sympatric species, as they occur in the same area and time, exhibiting very similar morphologic and anatomic features. *A. boyeri* is a truly resident euryhaline species (Elliott & Dewailly, 1995; Quignard & Pras, 1986) living mainly in brackish water lagoons and estuaries, in the Mediterranean region, Black Sea, Aral Sea, Caspian Sea and along the Atlantic coast (from southern Spain to Morocco) (Quignard & Pras, 1986). *A. presbyter* is a migrant species, which uses estuaries and coastal lagoons primarily as a nursery ground. Much of its adult life is spending at sea, but often returning seasonally to the estuary (Elliott & Dewailly, 1995). It's a pelagic fish inhabiting near surface in the littoral zone, occurring along the European and African coasts of the Atlantic Ocean, from Kattegat (rare) and Scotland to Mauritania, and around Madeira, Canaries and Cape Verde Islands (Quignard & Pras, 1986; Lorenzo & Pajuelo, 1999).

In contrast with *A. boyeri*, whose publications are very vast, published information about *A. presbyter* only consists on feeding aspects (Anadon, 1963; Kislalioglu & Gibson, 1977; Turnpenny *et al*., 1981; Lens, 1986; Moreno & Castro, 1995), morphometry, genetic and systematic aspects (Schultz, 1948; Bamber & Henderson, 1985; Quignard & Pras, 1986; Creech, 1991, 1992), and geographical distribution (Quignard & Pras, 1986; Maugé, 1990).

The taxonomic identification of these two species by the number of scales in longitudinal series and number of vertebrae (Quignard & Pras, 1986; Bauchot & Pras, 1987) is ambiguous and leads to some doubts. Bamber & Henderson (1985) proposed the synonymy of *A. presbyter* with *A. boyeri*. Marfin (1982) and Focant *et al*. (1999) also proposed polymorphism in *A. boyeri*. Recent studies approaching ecological, age and growth aspects (Fernandez-Delgado *et al*., 1988; Leonardos *et al*., 1993; Rosecchi & Crivelli, 1992, 1995; Lorenzo & Pajuelo, 1999; Leonardos, 2001; Leonardos & Sinis, 2000; Pajuelo & Lorenzo, 2000; Pombo *et al*., 2002 c) and morphological, morphometric, biochemical and genetic characteristics (Creech, 1991; Creech, 1992; Bembenuti, 1993; Trabelsi *et al*., 1994; Vasil'eva, 1994; Congiu *et al*., 1997) have, however, demonstrated differences between the two populations, consistent with the existence of two species.

In the Ria de Aveiro recent studies (Rebelo, 1992; Cruz & Rebelo, 2000; Pombo & Rebelo, 2000, 2002; Pombo *et al*., 2002 a and c) demonstrate that ecological behaviour and biological features are markedly distinct in both species showing an evident selective spatial distribution with the age. *A. boyeri* occurs in different stages of the lifespan in the entire lagoon area. Juveniles occur dispersedly in space, with no apparent abiotic preference (Pombo *et al*., 2002 c). Older adults (2-3 years) occur with high abundance at the north and south edges of the lagoon, in winter (Pombo *et al*., 2002 c), for spawning (Fernández-Delgado *et al*., 1988; Rosecchi & Crivelli, 1992). The high vegetation and productivity of these regions provide high food sources and refuges to this critical lifespan period.

In general, *A. presbyter* occurs in the lagoon with almost twice-lower abundance than *A. boyeri* (Pombo *et al*., 2002 c). The juveniles of *A. presbyter* occur mostly at deep regions of the south edge of the lagoon, during autumn. In the second year of life, fish begin to migrate, to the entrance area when they are getting maturity for spawning (Pajuelo & Lorenzo, 2000; Pombo *et al*., 2002 c). With the increasing size (10-15 cm) and age (2-3 years) adult fish occurrence is restricted, with high abundance, to a particular area close to the sea, in mid-spring.

Biological features, as length, weight, growth and age are distinctive in both species. *A. boyeri* reaches 12 cm in 3 years while *A. presbyter* reaches 15 cm in 4 years. Using the Gulland's equation (Gulland, 1969): $W = a\ L^{b}$, where W is the total body weight (g), L is the total length (cm), and a and b are the regression coefficients, $W=3.3\times10^{-3}.L^{3.35}$, for *A. boyeri* and $W=5.5\times10^{-3}.L^{3.09}$, for *A. presbyter*. *A. boyeri* growth in length is generally slow and lower than *A. presbyter*, except during the juvenile period (Pombo *et al*., 2002 c). Atherinids, in general, experienced a fast early growth rate through the first year of age (Fernandez-Delgado *et al*., 1988; Creech, 1992; Leonardos & Sinis, 2000), after which the annual growth rate drops rapidly, resulting of less energy available for somatic growth associated to sexual maturity (Pajuelo & Lorenzo, 2000).

All the basic functions of an organism (growth, maintenance and reproduction) consist with the spending of energy. Feeding is the main source of energy, being one of the most important functions (Valente, 1992). The knowledge of the diet of fish occurring in the natural environment is essential for the

understanding of its growth rate, reproduction and the whole behaviour, as the migrations (Kara & Derbal, 1996). Almost all the studies about fish alimentary habits are based on the stomach contents analyses, constituting the base of a great variety of knowledge about the ecology, production and ecological role of fish populations (Valente, 1992; Marshal & Elliott, 1997). According to Nikolsky (1963), fish can be classified as euryphagic, stenophagic, or monophagic, depending on the variety of the food consumed. Furthermore, Azevedo (1995) classifies fish as herbivorous, macro or micro-omnivorous, or macro, meso or micro-carnivorous, according to the type of prey consumed.

Previous studies on the diet of Atherinids are restricted to one of the two species analysed here (Anadon, 1963; Turnpenny *et al*., 1981; Ferrari & Rossi, 1984; Lens, 1986; Mirto *et al*., 1994; Moreno & Castro, 1995). The novelty of this study was to compare qualitative and quantitative dietary of *Atherina boyeri* and *Atherina presbyter*, with spatial and foraging behaviour patterns, and to determine their diet overlap in order to analyse biotic relationships, such as competition, and mainly emphasise distinct behaviour features, as food strategy.

Material and Methods

Study Area

The Ria de Aveiro (Fig. 1), on the west coast of Portugal, is a coastal estuarine lagoon with a maximum length of 45 km, maximum width of 11 km, and covering a total area between 42 km² (low tide) and 47 km² (high tide). The water volume is 70 million m^3, with an oceanic tidal contribution between 25 million m^3 (neap-tides) and 90 million m^3 (higher spring tides). Four rivers (Vouga, Antuã, Caster and Boco) and uncounted streams flow into it at a rate between 3 $m^3\ s^{-1}$ and 60 $m^3\ s^{-1}$, depending on the seasonal precipitation and run-off patterns (Barrosa, 1980). The mean substratum is silt, however sandy close to the lagoon's mouth and with immersed vegetation in the north edge. The industrial and fishing ports, the industries and population in the watershed are sources of three main pollution types: organic and chemical pollution, chemical pollution, and microbial contaminants (Barrosa, 1980; Lucas *et al*., 1986; Borrego *et al*., 1994).

Salinity, pH, turbidity and depth show extensive spatial statistically significant variations along sites (Pombo & Rebelo, 2000, 2002). Salinity varies from typically freshwater (ARE and RIO), brackish water (VAG, LAR and CAR), and marine water (BAR, SJA, GAF and TOR) close to the mouth of the lagoon (Fig. 1). pH varies between acid (6.81) in the areas with higher chemical pollution problems, especially Hg concentrations, from the industrial complex of Estarreja (LAR) (Fig. 1) (Pombo *et al*., 2000) and alkaline (9.62) in the areas with urban effluents and farming activities (Ílhavo channel, Vouga River and Ovar channel) (VAG, RIO and CAR) (Fig. 1). Turbidity varies between 20 cm at the edges of the lagoon and 2 m, near the mouth of the lagoon, where the currents are stronger. Depth varies between 0.5 m (ARE and TOR and 6 m (RIO, VAG and LAR) (Fig. 1). Temperature varies between 4 and 27 ºC; and dissolved oxygen varies from levels near the anoxia (4 mg.l^{-1}) to oversaturated values (13 mg.l^{-1}). The differences of temperature and dissolved oxygen are significant among months (Pombo & Rebelo, 2000, 2002) but not among sites.

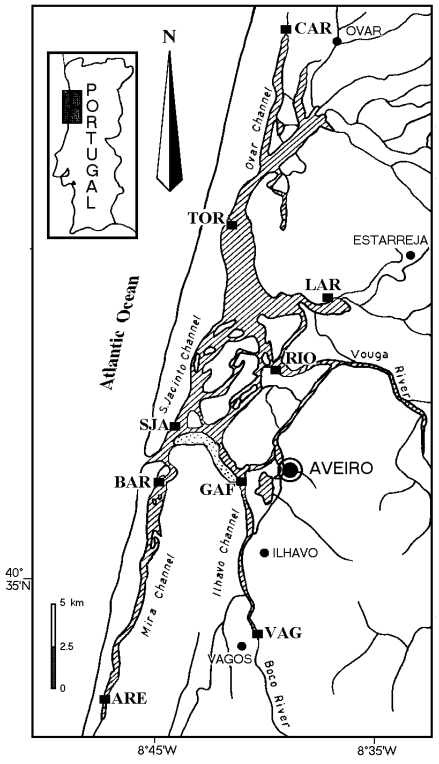

Fig. 1. – Map of the Ria de Aveiro lagoon, showing the sampling stations.

Concerning the availability of fish food within the lagoon, the analyses of spatial frequency of different groups of zooplankton (Morgado, 1997), show that copepods are the most dominant group in the whole lagoon. Decapods, isopods, mysids and amphipods are very abundant in most areas, while ostracods abundance is restricted to the middle of main channels, and oligochaetes and cumaceans are generally less abundant (Morgado, 1997). It was also shown that there was a significant interaction between behavioural strategies of zooplankton and cyclic changes of environmental conditions. The density of the major dominant neritic zooplankton species was significantly correlated with salinity, while for estuarine species the density was significantly correlated with water temperature (Morgado,

1997). Other important study on peracaridan crustaceans recorded 69 species in the whole lagoon comprising 52% amphipods, 19% isopods, 19% mysids, 6% cumaceans, and 4% tanaids (Cunha, 1999) and also showed important spatial and temporal changes. Amphipods dominated the upper reaches' assemblage in Ovar channel whereas mysids were dominant in the lower and middle reaches of the channel and all over the Mira channel. On the whole, mysids were dominant during winter and spring and amphipods during summer and autumn. Isopods had an important portion of the community in the upper reaches of both channels during all the year. Tanaids reached high densities in the middle reaches of Mira, but only in autumn and spring (Cunha, 1999).

Field Sampling

Fish were monthly sampled, from November 1998 to November 1999, at nine sampling sites (Fig. 1): near the mouth of the lagoon (BAR, GAF and SJA); at the edges of the main channels (ARE, CAR and VAG); in the main freshwater area, highly organically enriched (RIO); in the region of higher levels of industrial pollution (LAR), and approximately in the middle of the longest channel (TOR).

Samples were taken in triplicate, at low tide, with "chincha", a traditional beach-seine net. Fishes were preserved by freezing. In the laboratory, each specimen was identified according to Quignard & Pras (1986) and Bauchot & Pras (1987), and otoliths and stomachs were removed.

Otoliths and Dietary Contents

Otoliths were examined with a stereo microscope (*Olympus SZ60-PT*) and the age was estimated through the counting of translucent zones (summer rings, with a dark appearance under reflected light). Digestive tracts were dissected and stomachs were weighted with an electronic scale (*And-HR-60*) to the nearest 0.0001 g, before and after extraction of the stomach content, which was preserved in a 70% ethanol solution for later analysis.

Dietary contents were analysed according to Hayward & Ryland, (1998), with a stereo microscope (*Olympus SZ60-PT*) (630x) and an optic microscope (*Olympus CH 30*) (1000x). In spite of prey have been identified to the lowest

taxonomic level, they were grouped into categories in order to make the interpretation of data more clear. Thus, it was considered annelids, gastropods, bivalves, insects, crustaceans, algae, detritus and eggs. As crustaceans constitute a large group, 4 sub-groups were considered: the microcrustaceans (Cumacea, Copepoda, Ostracoda and larvae), small benthic crustaceans (Isopoda and Amphipoda), small pelagic crustaceans (Mysidacea) and macrocrustaceans (Decapoda) (table 1).

Data Analysis

The level of identification of food items is a function of the digestion stage of prey (Rosecchi & Nouaze, 1985). To evaluate the amount of each prey, some rules were considered: i) some items, like algae and unidentifiable material, were considered as a single unit (Arias, 1980); ii) some invertebrates as annelids, as they are rapidly digested, appeared in fragments or as a semi-digested mass; but they were considered as a single unit as well (Ktari *et al*., 1978); iii) the number of some crustaceans, such as mysids, was determined by dividing the number of dispersed eyes by two (Kara & Derbal, 1996); iv) other crustaceans were identified and counted from some parts of the body that allow their individualization, as the heads for amphipods, or cephalothoraxes or abdomina for mysids and decapods (Kara & Derbal, 1996); v) a small number of other items found in stomachs (e.g. molluscs shells and both larval and post larval crustaceans, and parasitic worms) were considered as miscellaneous or non-food items, probably ingested incidentally in normal feeding; vi) prey too digested for unequivocal identification to the lowest taxonomic level were assigned as n.i. (non-identified prey) (table 1).

For diet quantitative analysis, frequency of occurrence of a given prey type was defined as the number of stomachs in which that prey occurs, expressed as a frequency of a total number of stomachs in which prey are present (Hyslop, 1980). Prey-specific abundance was defined as the percentage a prey taxon comprises of all prey items in only those predators in which the actual prey occurs (Costello, 1990). The weight of prey items was not considered, since samples came from hauls conducted during different hours of the day and hence the digestion degree of the organisms ingested was different.

Table 1 - List of taxonomically identified prey group for *A. boyeri* and *A. presbyter* with number of individual prey items (Ni), percentage of frequency of occurrence (FO), percentage of prey-specific abundance (Pi), grade feeding preference classification (GFP), total stomachs analysed with identified prey, and empty stomachs. ni - non-identified, Sec - secondary prey, Oc - occasional prey.

Species	*A. boyeri*				*A. presbyter*			
Prey	Ni	FO (%)	Pi (%)	GFP	Ni	FO (%)	Pi (%)	GFP
Annelida	148	31.4	29.7	Sec.	519	35.1	49.1	Sec.
Polychaeta	21	7.4	19.6	Oc.	57	10.1	19.7	Oc.
Annelida n.i.	127	31.5	30.4	Oc.	462	29.7	54.4	Oc.
Mollusca								
Gastropoda	90	4.5	31.2	Oc.	138	7.3	41.6	Oc.
Bivalvia	329	9.9	81.0	Oc.	583	20.0	59.0	Oc.
Artropoda								
Insecta	87	21.1	16.7	Oc.	255	25.3	30.5	Oc.
Formicidae	-	-	-	-	26	0.8	57.8	Oc.
Insecta larva	35	10.0	10.4	Oc.	55	7.3	26.6	Oc.
Insecta n.i.	52	11.2	28.7	Oc.	174	17.4	30.4	Oc.
Phylum Crustacea								
Microcrustacea	366	10.0	73.9	Oc.	248	7.0	58.2	Oc.
Cumacea	6	0.4	31.6	Oc.	3	0.6	8.1	Oc.
Ostracoda	10	1.7	18.5	Oc.	18	1.7	47.4	Oc.
Copepoda	350	7.9	79.4	Oc.	226	4.5	65.0	Oc.
Crustacea larvae	-	-	-	-	1	0.3	33.3	Oc.
Small benthic crustacea	440	33.5	54.0	Sec.	579	27.5	55.3	Oc.
Gnatia sp.	-	-	-	-	8	0.6	30.7	Oc.
Idotea sp.	7	1.2	50.0	Oc.	6	1.4	6.5	Oc.
Sphaeroma sp.	417	31.0	50.1	Oc.	459	24.7	60.0	Oc.
Isopoda n.i.	1	0.4	11.1	Oc.	6	0.8	46.2	Oc.
Ampithoe sp.	-	-	-	-	1	0.3	50.0	Oc.
Corophium sp.	-	-	-	-	1	0.3	4.3	Oc.
Gammarus sp.	-	-	-	-	6	0.6	35.3	Oc.
Amphipoda n.i.	15	2.5	57.5	Oc.	92	4.5	32.4	Oc.
Small pelagic crustacea	33	7.0	37.5	Oc.	58	9.6	21.2	Oc.
Gastrosaccus sp.	3	0.41	42.9	Oc.	6	0.3	100.0	Oc.
Neomysis sp.	-	-	-	-	1	0.3	50.0	Oc.
Praunus flexuosus	5	0.8	55.6	Oc.	4	0.6	50.0	Oc.
Mysidacea n.i.	25	6.6	33.8	Oc.	47	8.7	17.0	Oc.
Macrocrustacea	7	0.8	77.8	Oc.	12	1.7	30.8	Oc.
Crangon crangon	7	0.8	77.8	Oc.	6	1.1	30.0	Oc.
Decapoda n.i.	-	-	-	-	6	0.6	22.2	Oc.
Crustacea n.i.	74	12.4	42.8	Oc.	92	13.8	32.6	Oc.
Algae	21	8.3	13.1	Oc.	26	6.5	37.7	Oc.
Detritus	15	4.1	78.9	Oc.	26	4.5	68.4	Oc.
Eggs	42	5.4	20.3	Oc.	130	5.3	62.0	Oc.
Total stomachs analysed	346				493			
Empty stomachs	1				2			
Total stomachs with identified prey	246				355			
Total of identified prey	1652				2666			

The feeding strategy (Fig. 2) was analysed using the new approach of the modified Costello method (Amundsen *et al*., 1996), which consists on a bidimensional graphical representation where each point represents the frequency of occurrence and the prey-specific abundance of a prey taxon. In this method the two diagonals of the plot represent prey importance (dominant-rare) and predator feeding strategy (specialization-generalized) (Amundsen *et al*., 1996).

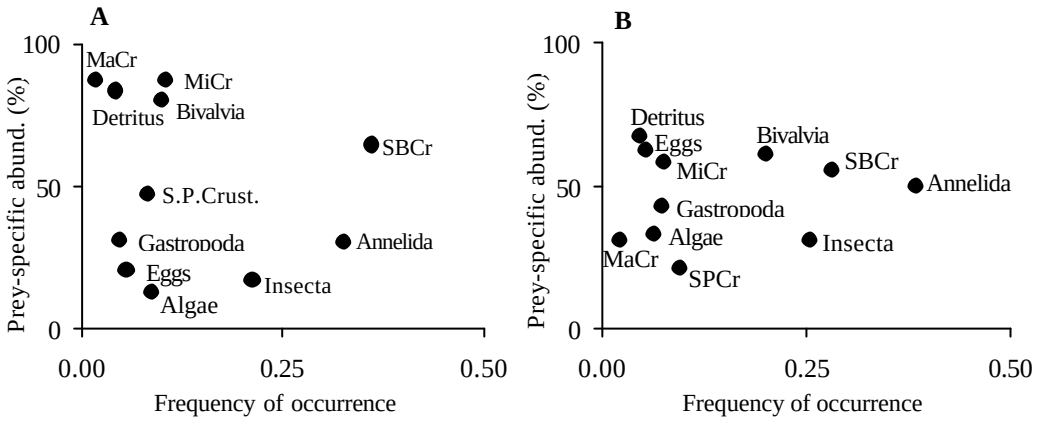

Fig. 2 - Prey-specific abundance per frequency of occurrence (modified Costello method) (Amundsen *et al*., 1996) for **A** – *A. boyeri* and **B** – *A. presbyter.* MiCr - Microcrustacea, SBCr - Small benthic crustacean, SPCr - Small pelagic crustacean, MaCr - Macrocrustacea.

Prey points close to 100% occurrence and 100% abundance represents the dominant prey taxa. Prey with high specific abundance and low occurrence or vice-versa are related to the between- and within-phenotype contributions to the niche width. High between-phenotype contribution (BPC), with points close to 1% occurrence and 100% abundance, is indicative of a specialization on certain taxa by some predators, i.e., different individuals specialize on different resource types, whereas high within-phenotype contribution (WPC), with points clustered close to 100% occurrence and 1% abundance, is indicative of a generalized diet, i.e., most of the individuals utilize many resource types simultaneously (Amundsen *et al*., 1996).

As volumetric values for stomachs contents were not possible, the grade of feeding preference (GFP) according to Braga, (1999) was calculated at each site. This method describes the feeding of fish using a simple description and computation of food item preferences. $GFP=S_{(i)}/N$, where $S_{(i)}$ is the sum of the

attributed values to the abundance of food item **i** in the stomachs, and N is the total number of analyzed stomachs. Thus, the estimated values for GFP of each food item are classified as: "absolute preferential prey" (Abs.), if GFP=4; "prey with high grade of preference" (HGP), if 3≤ GFP <4; "preferential prey" (Pref.), although other items are also consumed, if 2≤ GFP <3; "secondary prey" (Sec.), if 1≤ GFP <2; and "occasional prey" (Oc.), if 0≤ GFP <1 (Tables 1, 2 A, and 2 B).

Fish abundance, fish biomass and prey abundance was statistically tested in each species among sites, and among age, using one-way ANOVA (Zar, 1984; Sokal & Rohlf, 1995). Multiple paired t-tests were used to determine if whether any sites, and any age-groups, were different in each species (Zar, 1984; Sokal & Rohlf, 1995). The package Sigma-stat for windows version 2.03 was used for these analyses.

The diet breadth was estimated using the Levins' index $B = \frac{1}{\sum p_j^2}$, where p_j represents the proportion of the diet comprising prey species *j*. After measuring the Levins' index, it was preceded to the standardization in order to express the niche breadth on a scale from 0 to 1.0, low values indicate diets dominated by few prey items (specialist predators) and high values indicate generalistic diets (Hurlbert, 1978; Krebs, 1989). The used formula was $B_A = \frac{B-1}{n-1}$ where B_A is the Levins' standardized niche breadth; *B* is the Levins' measure of niche breadth and *n* represents the total number of prey species (Marshall & Elliott, 1997).

Diet overlap was calculated using the simplified Morisita's index (Krebs, 1989; Hall *et al*., 1990): $C_{ik} = (\sum jp_{ij}^2 + \sum jp_{kj}^2)^{-1}$, where C_{ik}= simplified Morisita's index for predator *i* and *k*; p_{ij} and p_{kj}=proportions of predator *i* and *k* with prey *j* in their fore-guts.

Diet overlap increases as the Morisita's index increases from 0 to 1. Overlap is generally considered to be biologically significant when the value exceeds 0.6 (Langton, 1982; Labropoulou & Eleftheriou, 1997 in Xie *et al*., 2000). One-way ANOVA was used to examine statistical differences on spatial variation and on age variation in diet breadth of two species (Zar, 1984; Sokal & Rohlf, 1995).

Table 2 A) - List of taxonomically identified prey group for *A. boyeri* with number of individual prey items (Ni), frequency of occurrence (FO), and grade feeding preference classification (GFP) in each sampling site. Total abundance of fish, number of analysed stomachs, empty stomachs, stomachs with identified prey, and total abundance of identified prey. ni - non-identified, Pref - preferential prey, Sec - secondary prey, Oc - occasional prey.

Sampling sites	BAR			SJA			GAF			RIO			TOR			LAR			VAG			ARE			CAR		
Prey	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP
Annelida	2	33.3	Sec.	2	11.8	Oc.	10	25.8	Sec.	25	32.4	Sec.	6	31.3	Sec.	13	44.4	Sec.	53	39.2	Sec.	31	31.1	Oc.	6	20.0	Oc.
Polychaeta	-	-	-	-	-	-	2	6.5	Oc.	6	10.8	Oc.	-	-	-	7	38.9	Sec.	1	2.0	Oc.	5	8.9	Oc.	-	-	-
Annelida n.i.	2	33.3	Sec.	2	11.8	Oc.	8	22.6	Oc.	19	21.6	Oc.	6	31.3	Sec.	6	11.1	Oc.	52	37.3	Sec.	26	26.7	Oc.	6	20.0	Oc.
Mollusca																											
Gastropoda	-	-	-	5	5.9	Oc.	12	6.5	Oc.	5	2.7	Oc.	15	20.0	Oc.	-	-	-	48	3.9	Oc.	-	-	-	5	4.0	Oc.
Bivalvia	11	33.3	Sec.	7	11.8	Oc.	18	6.5	Oc.	2	5.4	Oc.	24	12.5	Oc.	-	-	-	2	3.9	Oc.	243	11.1	Oc.	22	24.0	Oc.
Artropoda																											
Insecta	2	33.3	Oc.	3	11.8	Oc.	11	22.6	Oc.	12	21.6	Oc.	1	6.3	Oc.	8	22.2	Oc.	8	13.7	Oc.	30	33.3	Oc.	12	20.0	Oc.
Formicidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Insecta larva	1	16.7	Oc.	1	5.9	Oc.	9	16.1	Oc.	3	8.1	Oc.	1	6.3	Oc.	3	11.1	Oc.	5	7.8	Oc.	8	13.3	Oc.	4	4.0	Oc.
Insecta n.i.	1	16.7	Oc.	2	5.9	Oc.	2	6.5	Oc.	9	13.5	Oc.	-	-	-	5	11.1	Oc.	3	5.9	Oc.	22	20.0	Oc.	8	16.0	Oc.
Phylum Crustacea																											
Microcrustacea	-	-	-	50	17.6	Oc.	10	6.5	Oc.	25	2.7	Oc.	149	50.0	Sec.	-	-	-	83	3.9	Oc.	49	13.3	Oc.	-	-	-
Cumacea	-	-	-	-	-	-	6	3.2	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	-	-	-	-	-	-	2	3.2	Oc.	-	-	-	4	6.3	Oc.	-	-	-	3	2.0	Oc.	1	2.2	Oc.	-	-	-
Copepoda	-	-	-	50	17.6	Oc.	2	3.2	Oc.	25	2.7	Oc.	145	50.0	Sec.	-	-	-	80	2.0	Oc.	48	11.1	Oc.	-	-	-
Crustacea larvae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Small benthic crustacea	-	-	-	1	5.9	Oc.	5	6.5	Oc.	58	40.5	Sec.	3	12.5	Oc.	13	27.8	Oc.	188	51.0	Sec.	122	46.7	Sec.	50	40.0	Sec.
Gnatia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Idotea sp.	-	-	-	-	-	-	5	6.5	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	4.0	Oc.
Sphaeroma sp.	-	-	-	-	-	-	-	-	-	57	40.5	Sec.	2	6.3	Oc.	13	27.8	Oc.	188	51.0	Sec.	122	46.7	Sec.	35	32.0	Oc.
Isopoda n.i.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4.0	Oc.
Ampithoe sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Corophium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gammarus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphipoda n.i.	-	-	-	1	5.9	Oc.	-	-	-	1	2.7	Oc.	1	6.3	Oc.	-	-	-	-	-	-	-	-	-	12	12.0	Oc.
Small pelagic crustacea	3	33.3	Oc.	2	11.8	Oc.	11	12.9	Oc.	4	5.4	Oc.	-	-	-	3	11.1	Oc.	3	3.9	Oc.	7	8.9	Oc.	-	-	-
Gastrosaccus sp.	-	-	-	-	-	-	-	-	-	3	0.4	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Neomysis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Praunus flexuosus	-	-	-	-	-	-	2	3.2	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	3	2.2	Oc.	-	-	-
Mysidacea n.i.	3	33.3	Oc.	2	11.8	Oc.	9	12.9	Oc.	1	2.7	Oc.	-	-	-	3	11.1	Oc.	3	3.9	Oc.	4	6.7	Oc.	-	-	-
Macrocrustacea	-	-	-	-	-	-	-	-	-	1	2.7	Oc.	-	-	-	-	-	-	-	-	-	6	2.2	Oc.	-	-	-
Crangon crangon	-	-	-	-	-	-	-	-	-	1	2.7	Oc.	-	-	-	-	-	-	-	-	-	6	2.2	Oc.	-	-	-
Decapoda n.i.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crustacea n.i.	-	-	-	2	5.9	Oc.	6	6.5	Oc.	26	5.4	Oc.	3	6.3	Oc.	5	11.1	Oc.	10	9.8	Oc.	19	11.1	Oc.	3	8.0	Oc.
Algae	-	-	-	4	17.6	Oc.	1	3.2	Oc.	4	10.8	Oc.	2	12.5	Oc.	-	-	-	9	15.7	Oc.	1	2.5	Oc.	-	-	-
Detritus	-	-	-	-	-	-	2	6.5	Oc.	-	-	-	3	6.3	Oc.	-	-	-	7	9.8	Oc.	3	4.4	Oc.	-	-	-
Eggs	3	33.3	Sec.	6	11.8	Oc.	-	-	-	7	8.1	Oc.	-	-	-	6	11.1	Oc.	15	3.9	Oc.	2	2.2	Oc.	3	4.0	Oc.
Total abundance of fish	42			93			158			73			60			90			793			101			1093		
Total biomass of fish (g)	39			137			381			129			60			73			1568			232			3681		
Total number of analysed stomachs	7			20			65			59			25			29			60			49			32		
Empty stomachs	-			-			-			1			-			-			-			-			-		
Stomachs with identified prey	6			17			31			37			16			18			51			45			25		
Total abundance of identified prey	21			82			86			169			206			48			426			513			101		

Table 2B) - List of taxonomically identified prey group for *A. presbyter* with number of individual prey items (Ni), frequency of occurrence (FO), and grade feeding preference classification (GFP) in each sampling site. Total abundance of fish, number of analysed stomachs, empty stomachs, stomachs with identified prey, and total abundance of identified prey. ni - non-identified, Pref - preferential prey, Sec - secondary prey, Oc - occasional prey.

Sampling sites	BAR			SJA			GAF			RIO			TOR			LAR			VAG			ARE			CAR		
Prey	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP	Ni	FO	GFP
Annelida	96	17.1	Oc.	22	31.6	Oc.	137	36.0	Sec.	28	35.3	Sec.	68	57.9	Pref.	44	64.3	Sec.	54	25.6	Oc.	4	15.4	Oc.	66	40.0	Sec.
Polychaeta	7	17.1	Oc.	1	2.6	Oc.	8	5.4	Oc.	10	29.4	Oc.	4	7.9	Oc.	27	50.0	Sec.	-	-	-	-	-	-	-	-	-
Annelida n.i.	89	29.3	Oc.	21	28.9	Oc.	129	31.5	Sec.	18	17.6	Oc.	64	52.6	Sec.	17	17.9	Oc.	54	25.6	Oc.	4	15.4	Oc.	66	40.0	Sec.
Mollusca																											
Gastropoda	4	4.9	Oc.	36	13.2	Oc.	62	9.0	Oc.	-	-	-	4	7.9	Oc.	-	-	-	28	10.3	Oc.	1	7.7	Oc.	3	3.3	Oc.
Bivalvia	264	43.9	Sec.	28	23.7	Oc.	260	27.9	Oc.	7	5.9	Oc.	5	10.5	Oc.	1	3.6	Oc.	10	5.1	Oc.	5	15.4	Oc.	3	6.7	Oc.
Artropoda																											
Insecta	18	29.3	Oc.	12	18.4	Oc.	85	25.2	Oc.	20	23.5	Oc.	16	23.7	Oc.	24	21.4	Oc.	38	28.2	Oc.	29	53.8	Sec.	13	20.0	Oc.
Formicidae	-	-	-	-	-	-	26	2.7	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Insecta larva	4	7.3	Oc.	4	5.3	Oc.	13	6.3	Oc.	2	5.9	Oc.	2	5.3	Oc.	1	3.6	Oc.	24	12.8	Oc.	-	-	-	5	10.0	Oc.
Insecta n.i.	14	22.0	Oc.	8	13.2	Oc.	46	17.1	Oc.	18	17.6	Oc.	14	18.4	Oc.	23	17.9	Oc.	14	15.4	Oc.	29	53.8	Sec.	8	10.0	Oc.
Phylum Crustacea																											
Microcrustacea	132	14.6	Oc.	-	-	-	91	11.7	Oc.	-	-	-	-	-	-	10	3.6	Oc.	2	2.6	Oc.	13	23.1	Oc.	-	-	-
Cumacea	2	2.4	Oc.	-	-	-	1	0.9	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	-	-	-	-	-	-	18	5.4	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copepoda	130	12.2	Oc.	-	-	-	71	5.4	Oc.	-	-	-	-	-	-	10	3.6	Oc.	2	2.6	Oc.	13	23.1	Oc.	-	-	-
Crustacea larvae	1	2.4	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Small benthic crustacea	11	19.5	Oc.	12	13.2	Oc.	76	17.1	Oc.	52	29.4	Sec.	9	13.2	Oc.	108	35.7	Sec.	174	59.0	Pref.	45	61.5	Pref.	92	33.3	Sec.
Gnatia sp.	-	-	-	7	2.6	Oc.	1	0.9	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Idotea sp.	-	-	-	-	-	-	5	3.6	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	1	7.7	Oc.	-	-	-
Sphaeroma sp.	6	9.8	Oc.	3	7.9	Oc.	66	11.7	Oc.	38	23.5	Oc.	9	13.2	Oc.	102	35.7	Sec.	174	59.0	Pref.	44	61.5	Pref.	17	26.7	Oc.
Isopoda n.i.	-	-	-	2	2.6	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	3.3	Oc.
Ampithoe sp.	-	-	-	-	-	-	1	0.9	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Corophium sp.	1	2.4	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gammarus sp.	-	-	-	-	-	-	-	-	-	4	5.9	Oc.	-	-	-	2	3.6	Oc.	-	-	-	-	-	-	-	-	-
Amphipoda n.i.	4	9.8	Oc.	-	-	-	3	2.7	Oc.	10	17.6	Oc.	-	-	-	4	3.6	Oc.	-	-	-	-	-	-	71	16.7	Oc.
Small pelagic crustacea	4	7.3	Oc.	2	5.3	Oc.	15	11.7	Oc.	10	29.4	Oc.	6	10.5	Oc.	14	14.3	Oc.	3	7.7	Oc.	4	15.4	Oc.	-	-	-
Gastrosaccus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	7.1	Oc.	-	-	-	-	-	-	-	-	-
Neomysis sp.	-	-	-	-	-	-	1	0.9	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Praunus flexuosus	-	-	-	-	-	-	-	-	-	1	5.9	Oc.	-	-	-	-	-	-	-	-	-	3	7.7	Oc.	-	-	-
Mysidacea n.i.	4	7.3	Oc.	2	5.3	Oc.	14	10.8	Oc.	9	23.5	Oc.	6	10.5	Oc.	8	7.1	Oc.	3	7.7	Oc.	1	7.7	Oc.	-	-	-
Macrocrustacea	3	4.9	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	3	10.7	Oc.	6	2.6	Oc.	-	-	-	-	-	-
Crangon crangon	3	4.9	Oc.	-	-	-	-	-	-	-	-	-	-	-	-	2	3.6	Oc.	1	2.6	Oc.	-	-	-	-	-	-
Decapoda n.i.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	3.6	Oc.	5	2.6	Oc.	-	-	-	-	-	-
Crustacea n.i.	6	12.2	Oc.	36	21.1	Oc.	22	16.2	Oc.	-	-	-	7	15.8	Oc.	3	7.1	Oc.	7	15.4	Oc.	11	-	Sec.	-	16.7	
Algae	4	9.8	Oc.	9	21.1	Oc.	2	1.8	Oc.	3	17.6	Oc.	4	10.5	Oc.	1	3.6	Oc.	3	7.7	Oc.	-	-	-	-	-	-
Detritus	3	4.9	Oc.	2	2.6	Oc.	7	6.3	Oc.	1	5.9	Oc.	-	-	-	1	3.6	Oc.	4	5.1	Oc.	-	-	-	8	16.7	Oc.
Eggs	54	9.8	Oc.	7	13.2	Oc.	14	5.4	Oc.	28	11.8	Oc.	-	-	-	1	3.6	Oc.	24	2.6	Oc.	-	-	-	2	3.3	Oc.
Total abundance of fish	92			96			535			16			81			133			158			12			46		
Total biomass of fish (g)	773			327			3819			113			331			1164			678			24			436		
Total number of analysed stomachs	52			62			102			37			68			37			61			35			39		
Empty stomachs	-			-			1			-			-			1			-			-			-		
Stomachs with identified prey	41			38			111			17			38			28			39			13			30		
Total abundance of identified prey	600			166			770			149			119			210			353			112			187		

Results

Feeding Strategy

For the purpose of the present study a total of 346 stomachs of *A. boyeri* and 493 stomachs of *A. presbyter* were analysed, from which only 1 and 2 were empty respectively in *A. boyeri* and *A. presbyter*. The values of frequency, prey-specific occurrence, number and the grade of feeding preference classification of all

categories of prey are reported in Table 1. For these calculations, only 246 stomachs were considered for *A. boyeri* and 355 for *A. presbyter*, the remaining stomachs contained only prey completely digested that were not possible to identify (Table 1).

Both species consumed a considerable variety of food items from different groups: worms (Annelida), molluscs (Bivalvia and Gastropoda), insects, crustaceans (Cumacea, Ostracoda, Copepoda, Isopoda, Amphipoda, Mysidacea and Decapoda), algae, detritus and eggs. Small benthic crustaceans were the most important prey for *A. boyeri*, being considered a secondary prey (i.e. the prey was irregularly consumed by a large number of individuals), representing 34% of frequency of occurrence, (Table 1 and Fig. 2A) and annelids were the most important prey for *A. presbyter*, being considered a secondary prey, representing 35% of frequency of occurrence (Table 1 and Fig. 2B). All the other categories were occasional prey, i.e. the prey was rarely consumed by a large number of individuals. Although the principal prey type consumed by the two fish species was different, they had both taken a considerable number of small benthic crustaceans, the occurrence varied from 28% for *A. presbyter* to 34% for *A. boyeri*, and bivalves varying from 10% for *A. boyeri* to 20% for *A. presbyter* (Table 1). Within small benthic crustaceans, *Sphaeroma sp.* (Isopoda) was the most representative species for both Atherinids (31% of frequency of occurrence for *A. boyeri* and 25% for *A. presbyter*) (Table 1). Annelids occupy a second place in the diet for *A. boyeri*. This item appeared in 32 % of analysed stomachs (Table 1) and also composed a secondary item for this species, showing a relatively low prey-specific abundance (30 % of prey-specific abundance) (Fig. 2A). Insects occupied the third place in diet of both species (Table 1 and Figs. 2A and 2B). This item represented 21 % of frequency of occurrence for *A. boyeri* and 25 % for *A. presbyter*.

For *A. boyeri*, the items, which highly contributed to the width of their ecological niches (high BPC (between-phenotype component to niche width)), were macrocrustaceans (Fig. 2A), with relevance to *Crangon crangon*, and detritus (78 % and 79 % of prey-specific abundance, respectively) (Table 1) i.e. it was characteristic of the diet of this species, leading to a high prey-specific abundance and low frequency of occurrence. On the other hand, for *A. presbyter*, the food

items that contributed to a high BPC were detritus, eggs, and microcrustaceans (especially copepods and ostracods) (Fig. 2B) although with less prey-specific abundance than *A. boyeri* (68 % for detritus, 62 % for eggs, and 58 % for microcrustaceans) (Table 1).

The great variety of food consumed by these two species was largely due to the presence of many rare prey (with low frequency of occurrence and low prey-specific abundance), which can indicate that, in the absence of their preferential items, these species feed on every type of available resources. The group of rare prey for *A. boyeri* included eggs, gastropods, algae, and small pelagic crustaceans (Fig. 2A). The group of rare prey for *A. presbyter* included macrocrustaceans, algae, small pelagic crustaceans, and gastropods (Fig. 2B). It is important to note that macrocrustaceans contributed to a high BPC for *A. boyeri*, while constituted a rare prey for *A. presbyter* (Figs. 2A and 2B). The opposite occurs with the eggs group, which was a rare prey for *A. boyeri* but highly contributed to high BPC for *A. presbyter*. In both species, it was not found any food item, which could contribute to a high WPC (within-phenotype component) or any dominant prey, as the frequency of occurrence was not higher than 50 % for all the items.

A comparison of diet breadth of each species was achieved, the values obtained in the standardized Levins' measure was relatively low in both species, indicating reliance on a limited group of prey species (Fig. 3).

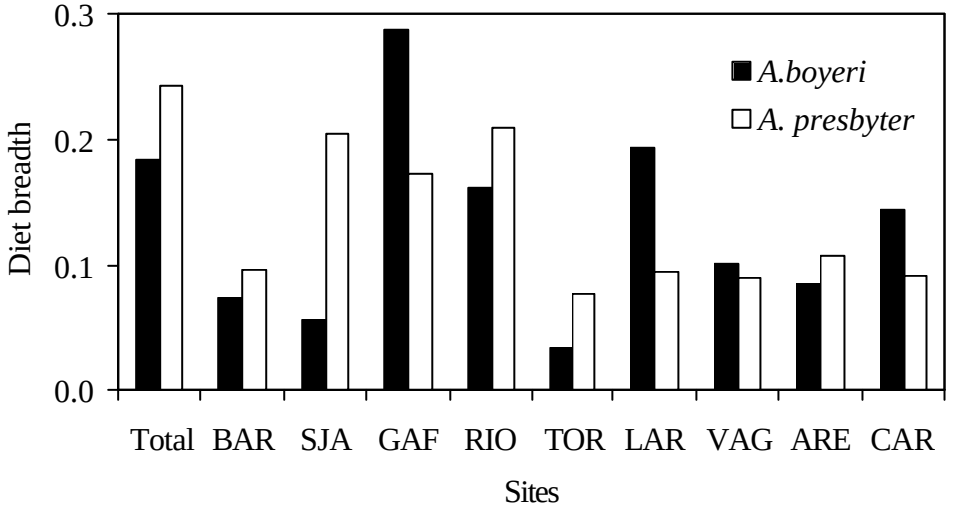

Fig. 3 - Spatial changes (total and sampling sites) in diet breadths for *A. boyeri* and *A. presbyter*.

The total diet overlap in the whole lagoon was significantly higher (0.8) than the biologically significant level (0.6) (Fig. 4).

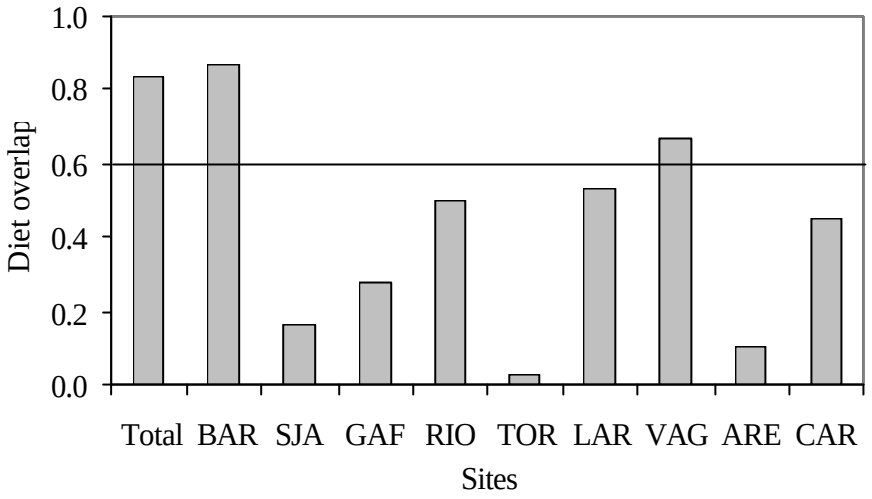

Fig. 4 - Spatial changes (total lagoon and sampling sites) in diet overlap between *A. boyeri* and *A. presbyter*.

With close correlations between high occurrence of food items in the diet and their abundance in the environment, it is suggested that food limitation in Ria de Aveiro, as a whole lagoon, was rare and the high diet overlaps between these two species did not indicate intensive interspecific competition. Although spatial variation of food resources and fish colonization will be needed to better understand their diet overlap and food interactions.

Spatial Variation in Diet

Analysis of the spatial occurrence of prey species in each fish species diet indicated statistically significant differences in the abundance of prey ($p=0.004$ for *A. boyeri* and $p=0.007$ for *A. presbyter*). Comparing both species, the abundance of prey was statistically different in three sites (BAR, GAF, and ARE) ($p<0.001$; $p= 0.014$; $p=0.031$, respectively). Abundance and biomass of fish were also significantly different in the same sites. Crustaceans were dominantly consumed by *A. presbyter* and rarely consumed by *A. boyeri* (Tables 2 A and 2 B) at BAR and GAF. Annelids and eggs constitute a secondary prey for *A. boyeri* at BAR, while are considered rare (or occasional) prey for *A. presbyter* (Tables 2 A and 2

B). Annelids, molluscs and insects were highly consumed by *A. presbyter* at GAF comparing to *A. boyeri*. Insects and crustaceans non-identified constitute secondary prey for *A. presbyter* at ARE, while are considered rare (or occasional) prey for *A. boyeri*; and small benthic crustaceans, namely *Sphaeroma sp*. are considered a preferential prey for *A. presbyter* and a secondary prey for *A. boyeri*, also at ARE.

Diet breadth was higher for *A. boyeri* at GAF, LAR, VAG and CAR (Fig. 3) and higher for *A. presbyter* in the other sites, but overall was higher for *A. presbyter*. Concerning the diet overlap, it was significantly higher than the biologically significant level (0.6) at BAR (0.9) and VAG (0.7). In the other sites, the values for dietary overlap between fish species were low (<0.6), indicating that they exploit different prey species, as they occur differently in the lagoon in different stages of life and diet overlap must also be interpreted in relation to the fluctuation of the resource base.

Fish Age Variation in Diet

From the total 346 analysed stomachs of *A. boyeri*, 41 were from the 0^+-age group, 55 from the 1^+-group, 88 from the 2^+-group, and 38 from the 3^+-group From the total 493 analysed stomachs of *A. presbyter*, 39 were from the 0^+-age group, 91 from the 1^+-group, 181 from the 2^+-group, and 21 from the 3^+-group (Table 3). The total 3 empty stomachs (1 for *A. boyeri* and 2 for *A. presbyter*) belonged to the 0^+-age group.

In general, the majority of food items were represented in all the age groups, in both species, in spite of their abundance being higher or lower in the different stages of life (Figs. 5A and 5B). There are some food items, which were only consumed by a certain age group. Within microcrustaceans, Cumacea, a very small prey, which satisfies small predators, was only consumed by 0^+-group (Table 3). The opposite occurs with macrocrustaceans (*Crangon crangon* and other decapods) that were mostly consumed by older individuals (mainly 2^+ and 3^+) (Table 3). *Praunus flexuosus* (Mysidacea) was only consumed by the 2^+-age group, in both studied species (Table 3). Growth was also associated with an increase in the diversity per stomach for both species, especially in the 2^+-age

group. This stage of life included the highest number of individuals analysed in both species, therefore this stage showed the largest variety of food items, comprising all the considered food groups (Figs. 5A and 5B) and the majority of the crustaceans subgroups (Table 3).

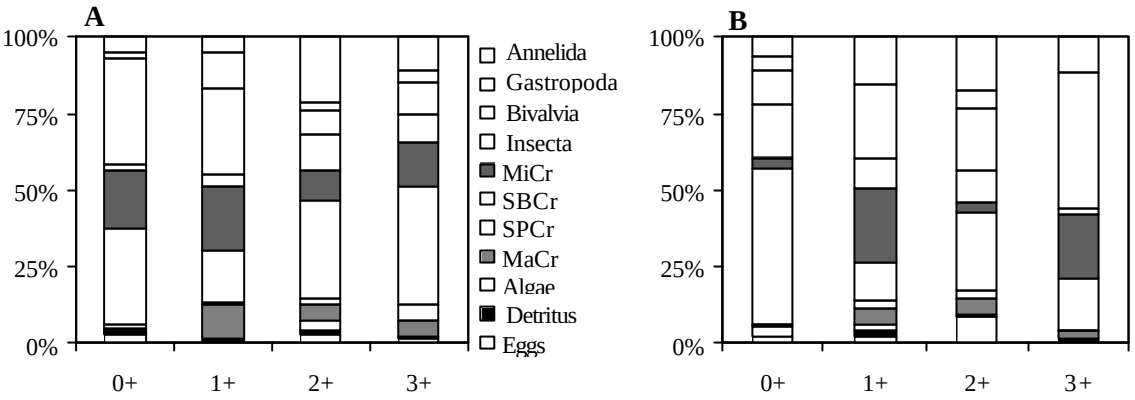

Fig. 5 - Diet composition of **A** – *A. boyeri* and **B** – *A. presbyter* according to fish age. MiCr - Microcrustacea, SBCr - Small benthic crustacean, SPCr - Small pelagic crustacean, MaCr - Macrocrustacea.

The number of prey (Ni) and the prey-specific abundance (Pi) varied significantly among the age classes for *A. presbyter* ($p<0.01$ for Ni, and $p=0.002$ for Pi), but that difference was not significant for *A. boyeri*. Comparing the diet of the two species, some food items were consumed in different abundance, along the age. Bivalves and insects evidenced an opposite preference for each species. *A. boyeri* significantly increased the feed on insects along the age and decreased the feed on bivalves along the age, and the opposite occurs for *A. presbyter* (Figs. 5A and 5B). Gastropods evidenced different abundance along the age in each species; older individuals of *A. boyeri* and younger individuals of *A. presbyter* mostly consumed this item.

Small pelagic crustaceans represented the highest prey-specific abundance (100 %), i.e. this item occurred in all the analysed stomachs for this group of age, in the 1^+-group, for *A. boyeri*, and in the 0^+-group for *A. presbyter*, persisting along all the age groups.

Diet breadth increased from 0^+-age group to the 2^+- age group but decreased in the 3^+- age group in both species (Fig. 6). Older individuals are rarer than younger ones, so the diversity and abundance of prey consumed was minor in both species.

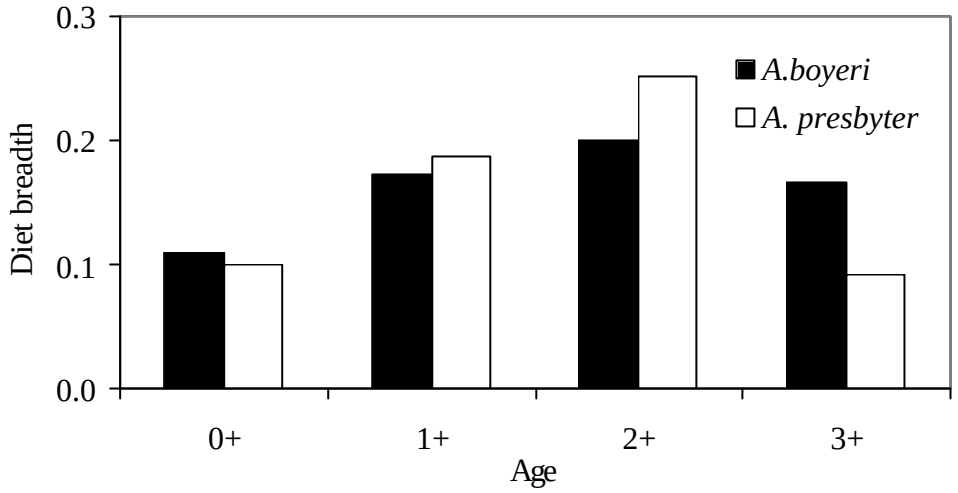

Fig. 6 - Age changes in diet breadth for *A. boyeri* and *A. presbyter*.

Diet overlap was higher than the biological meaning in 1^+ (0.8) and 2^+ (0.7) - age groups (Fig. 7), indicating that in those stages of age species exploit mainly the same type of food, but it is important to analyse the food resources and the distribution of the species along the lagoon in those different stages of age and the feeding strategies adopted by each species. Younger classes exhibited relatively low overlap between the two species as they occur in different environments at this stage of life with different food available resources.

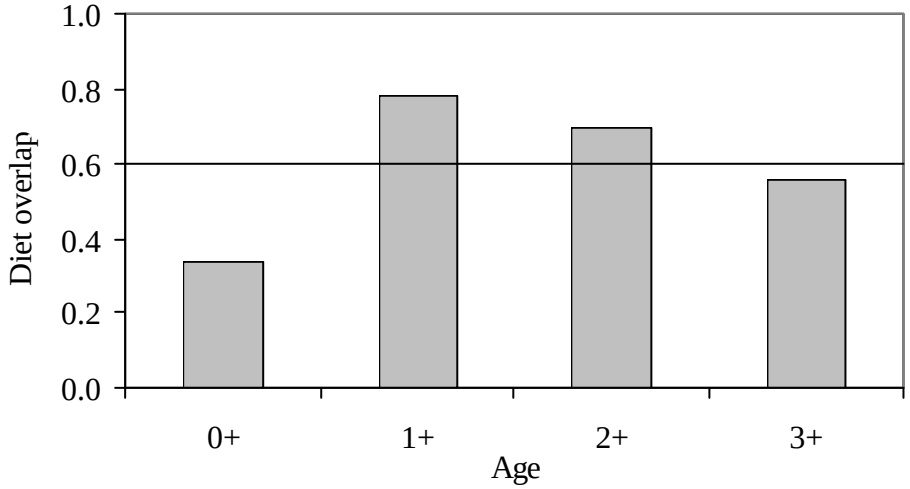

Fig. 7 - Age changes in diet overlap between *A. boyeri* and *A. presbyter*.

Discussion

Most of dietary components of *A. boyeri* and *A. presbyter* are pelagic but also benthic organisms, as annelids, small benthic crustaceans (amphipods and isopods), and molluscs (gastropods and bivalves). The apparent dominance of crustaceans in stomachs of fish reflects the preponderance of this taxon in the plankton, as Turnpenny *et al.* (1981) verified for *A. presbyter.* Small benthic crustaceans constitute a secondary prey for *A. boyeri* and annelids constitute a secondary prey in both Atherinids, being the most important prey for *A. presbyter* and the second most important prey for *A. boyeri.* According to Marshall (1971), the Atherinids show adaptations for feeding on the surface film. This behaviour was verified by Garcia (1994) and also in the present study, where insects constitute the third place in the diet of both species.

Previously, on account of the anatomy of fish, Atherinids have generally been considered planktivorous (Marfin, 1982; Alessio *et al.*, 1990; Garcia, 1994). Thus, Rosecchi & Crivelli (1992), for *A. boyeri*, and Turnpenny *et al.* (1981), for *A. presbyter*, reported a predominantly zooplanktivorous diet, which is according to this study, whose diets are based on small crustaceans. In terms of feeding habits, they are euryphagic (Nikolsky, 1963; Mirto *et al*., 1994), as they feed on a large variety of prey, which leads to a generalist food strategy.

The degree of fullness was very high and the number of empty stomachs was very low, probably because fish, although primarily microcarnivorous, include in their diet various species of annelids, molluscs, macrocrustaceans, algae, detritus, and eggs, which indicates a trophic plasticity, adapting the diet according to the availability of food in the environment (Alessio *et al*., 1990). This strategy affords a degree of opportunism in the feeding of sand-smelts (Turnpenny *et al.*, 1981).

A comparison of diet breadth reflects the generalised feeding strategy for both species, being higher for *A. presbyter*, whose diet tends to a specialization on detritus, eggs, and microcrustaceans in addition to a high variety of rare prey, including macrocrustaceans, leading to a more mixed feeding strategy comparing to *A. boyeri*. As *A. presbyter* grows faster than *A. boyeri* its gape length allows them to consume bigger prey, when they are available in the environment. This

fact is according to Fernandez-Delgado *et al*. (1988), Creech (1992), Leonardos & Sinis (2000), and Pombo *et al*., (2002 c) who evidenced that fish length composition was markedly different in both species: *A. presbyter* was bigger but thinner and its growth was fast and higher than *A. boyeri*, which may be related to its food preference for big prey. The results of this study are supported by those of Fernandez-Delgado *et al*., (1988), Rosecchi & Crivelli (1992), Tomasini *et al*., (1996), and Leonardos (2001), who concluded that *A. boyeri* had life history traits typical of a species in an unstable environment: low growth rate, except during the juvenile period, high mortality, early sexual maturation, extended breeding season and multiple spawning. Thus, in the event of drastic environmental changes, multiple spawning can allow at least a part of the breeding stock to survive (Rosecchi & Crivelli, 1992).

The general strategy of occupation of pelagic fish is based on high densities of individuals of the same species (Moreno & Castro, 1995). This strategy could reduce interspecific competition by space exclusion of other species. In the lagoon *A. boyeri* was in most microhabitats twice more abundant than *A. presbyter*. In the Camargue and elsewhere in France, *A. boyeri* is considered as a sedentary lagoon species (Marfin, 1982); however, many authors have emphasised the capacity of Atherinids for colonising freshwater habitats and Rosecchi & Crivelli, (1995) refers the capacity of making movements between the lagoon and the sea. The most important factors for these migrations are access to a food supply and absence of predators (Rosecchi & Crivelli, 1995). In Ria de Aveiro there are no records of movements of *A. boyeri* between the lagoon and the sea, which lead us to admit the sufficient food resource in the lagoon.

With close correlations between high occurrence of food items in the diet and their peaks of abundance in the environment, it is suggested that food limitation in Ria de Aveiro was rare and the high diet overlaps between these two species did not indicate intensive interspecific competition, as fish distribution within the lagoon and the food preference along the age was different.

A strong indication of spatial variation in dietary composition is the statistical difference in the biomass and number of fish colonizing the lagoon in three sites: near the mouth of the lagoon (Barra and Gafanha), and at the edge of the main

south channel (Areão). Near the mouth of the lagoon, with sandy bottom, high salinity, and strong currents, *A. presbyter* was more abundant, while in the south reaches, with low salinity, low depth and high abundance of vegetation and mysids, *A. boyeri* was more abundant in terms of number and biomass. Where differences in diet were observed, these differences indicate that extend of variation in prey consumption within a species is appropriate when examining general patterns of interspecific variation in diet and broad patterns of trophic structure. Analysis of variance of the other sites showed that the number and biomass of these two species were not significantly different and diet breadth of the species was also not significantly affected by sites. The diet overlap was only evident in two sites, near the mouth of the lagoon and at the southeast channel, where adults of both species co-habit with high abundance. They feed especially on bivalves near the mouth of the lagoon, and small benthic crustacean at the southeast channel, mainly *Sphaeroma sp.*

The majority of comparisons of intraspecific spatial variation in diet revealed little between sites differences in the diet and where differences did occur, they were most commonly due to one item being important in the diet of a species from one site but not in another. For example, while small benthic crustaceans were preferential prey for *A. presbyter* at the south of lagoon, they were secondary or essentially absent in the remaining sites. Similarly, annelids and molluscs were twice important in the diet of *A. boyeri* near the mouth of the lagoon than in other sites. Turnpenny *et al*. (1981) demonstrated that comparisons of stomach contents of *A. presbyter* over time revealed no significant change in diet, similarly there was no differentiation in diet between males and females; the only discernible change in dietary habit through the population, and through time, was associated with growth in length.

From the species found in stomachs and the minimum occurrence of algae it is apparent that the two species do not occur in the water body passively, but actively predate animals moving in the water, enabling it to select zooplankters from the general plankton and with increasing age, to supplement its diet with larger swimming animals, such as amphipods and decapods. This strategy affords a degree of opportunism in the feeding of sand-smelts (Turnpenny *et al*., 1981).

The greater proportion of larger fish with a high diversity on prey reflects the progression to natant macrofauna in the diet that occurs as fish become large enough to prey actively upon larger animals moving in the water body. Rosecchi & Crivelli (1992) and Ferrari & Rossi (1983) also recorded a progressive decrease in the importance of plankton in the diet with increasing age of fish.

The smaller-sized *A. boyeri* feed mainly on smaller benthic crustaceans (S*phaeroma sp.*), bivalves and microcrustaceans (copepods). As size increases, fish turn to a diet including nektoplankton (mysids and decapods) and macrobenthos (polychaetes and amphipods) but also detritus and a large amount of insects while the consumption of bivalves decreases.

The smaller-sized *A. presbyter* feed also mainly on smaller benthic crustaceans (S*phaeroma sp.*), and insects. As size increases, fish turn to a diet including a large amount of bivalves and microcrustaceans (copepods). Insects decrease in the diet while the consumption of bivalves increases.

The diet overlap of older individuals indicates that species feed mainly on the same type of food, but it is important to note that fish have different distribution areas. Adult fsh that occur mainly at the edges of lagoon, as *A. boyeri*, and manage to leave them, perhaps constitute an advantage over *A. presbyter* because of the richness of the zooplankton and immersed vegetation, which provide high food sources and refuges against eventual predators (Rosecchi & Crivelli, 1992). The general strategy of occupation of pelagic fish is based on high densities of individuals of the same species. This strategy could reduce interspecific competition by space exclusion of the other species (Moreno & Castro, 1995). *A. boyeri*, sustained by high concentrations of individuals of small size, is the best example of a coastal resident species. This species develops its life cycle in the same ecosystem, without apparent habitat changes. The use of coastal ecosystem during different periods of time is another strategy that reduces competition between species for food resources (Moreno & Castro, 1995). *A. presbyter* uses estuaries and lagoons primarily as a nursery ground (Elliott & Dewailly, 1995) remaining in the lagoon while they are getting maturity for spawning (Pajuelo & Lorenzo, 2000). Adult fish occurrence is restricted near the sea, with high abundance, in mid-spring. This species is characterized by a high

growth rate and probably has a swimming capacity and resistance (proper of a juvenile migrant species) higher than *A. boyeri*, which lives in the lagoon during all the life cycle. This strategy probably constitutes an advantage of *A. presbyter* over *A. boyeri*, especially when the lagoon starts to be depleted as juveniles can migrate offshore changing significantly their trophic strategy. At this time specimens have reached 10-15 cm total length and 2-3 years of age. Younger classes did not exhibit overlap between species, which is related to the spatial and temporal variations in food composition and available food resources (Moreno & Castro, 1995).

A description of food niches occupied by the fish fauna in general is to great extend dependant on the accuracy of the taxonomic classification of prey. Ideally, each type of prey needs to be identified according to species level to confirm or exclude any overlapping of food sources. Investigations of this sort are, however, generally unrealistic due to the advanced states of digestion or the condition of fragments found in the fish stomachs (Gröhsler, 1994). Thus, further information about feeding strategies in terms of specialization and generalization both at individual and population level will be needed.

It can be concluded that in spite of both Atherinids consumed the same food items, the ecologically different species, which use in the estuarine coastal lagoon in different ways, show distinct feeding strategies, which must not be strictly considered for the all life stages, because they could be restricted to a specific stage. The combination of different strategies gives a wider spectrum of the possibilities of exploitation of the coastal ecosystem food resource, thus reducing interspecific competition.

Acknowledgements

We would like to thank the *University of Aveiro* and the *Foundation for Science and Technology* for their financial support of this research. The authors are also very grateful to Karine Briand and Alfredo Rocha for their field and lab collaboration.

References

Alessio, G.; Baldaccini, G.N.; Bernori, E. & Duchi, A. 1990. Ricerche biologique sul latterino, *Atherina boyeri* Risso, nell'area Viareggina. *Riv. Idrobiol.,* 29 (1): 19-34.

Amundsen, P.A.; Gabler, H.M. & Staldvik, F.J. 1996. A new approach to graphical analysis of feeding strategy from stomach contents data – modification of the Costello (1990) method. *J. Fish Biol.*, 48: 607-614.

Anadon, E. 1963. Observaciones sobre bancos y conducta alimenticia de *Atherina presbyter* C, *Mugil provensalis* Risso, *Diplodus sargus* L y *Diplodus vulgaris. Geofir. Bol. R. Soc. Esp. Hist. Nat*., 61: 141-147.

Arias, A. 1980. Crecimiento, régime alimentario y reproduccion de la Dorada (*Sparus aurata* L) y del Robalo (*Dicentrarchus labrax* L) en los esteros de Cádiz. *Inv. Pesq.*, 44 (1): 59-83

Azevedo, J.N. 1995. Food web of the Azorean shallow water Marine Ichthyological Communities: A Guild Approach. *Bol. Mus. Mun. Funchal*, supl. 4: 29-53.

Bamber, R.N. & Henderson, P.A. 1985. Morphological variation in British atherinids, and the status of *Atherina presbyter* Cuvier (Pisces: Atherinidae). *Biol. J. Limn. Soc*., 25: 61-76.

Barrosa, J.O. 1980. A Ria de Aveiro e a sua influência na economia da região. *Recurs. Hídric*., 1 (3): 83-96.

Bauchot, M.L. & Pras, A. 1987. *Guía de los peces de mar de España y de Europa*. Ediciones Omega, Barcelona.

Bembenuti, M.A. 1993. Redescription of Odontesthes argentinensis (Valenciennes) Pisces: Atherinidae, from the Rio Grande do Sul Coast. *Atlantica Rio grande*, 15: 17-35.

Borrego, C.; Cruz, M.M. & Gonçalves, P. 1994. *Estudo de avaliação da vulnerabilidade da capacidade de recepção das águas costeiras em Portugal Relatório R 32 Meios receptores e suas características: (Be 1) - Ria de Aveiro, Pateira de Fermentelos e Barrinha de Mira.* Projecto nº 13/94. IDAD., Aveiro.

Braga, F.M.S. 1999. O grau de preferência alimentar: um método qualitativo e quantitativo para o estudo do conteúdo estomacal de peixes. *Acta Scientiarum,* 21(2): 291-291.

Congiu, L.; Bertelli, G. & Colombo, G. 1997. Genetic differences among populations of *Atherina boyeri*, Risso 1810, of Italian coastal lagoons, observed with the method of RAPD (Random Amplified Polymorphic DNA). *Biol. Mar. Mediterr.,* 4 (1): 478-480.

Costello, M.J. 1990. Predator feeding strategy and prey importance: a new graphical analysis. *J. Fish Biol.*, 36: 261-263.

Creech, S. 1991. An electrophoretic investigation of populations of *Atherina boyeri* Risso, 1810 and *A. presbyter* Cuvier, 1829 (Teleostei: Atherinidae): genetic evidence in support of the two species. *J. Fish Biol*., 39: 807-816.

Creech, S. 1992. A multivariate morphometric investigation of *Atherina boyeri* Risso, 1810 and *A. presbyter* Cuvier, 1829 (Teleostei: Atherinidae): morphometric evidence in support of the two species. *J. Fish Biol*., 41: 341-353.

Cruz, R. & Rebelo, J.E. 2000. Growth data in fish of the Ria de Aveiro. *Rev. Biol. (Lisboa)*, 18: 41-47.

Cunha, M.M.P.R. 1999. Peracaridan crustacea in Ria de Aveiro (NW Portugal): taxonomic composition and spatio-temporal structure of the assemblages; life history and secondary production of *Corophium multisetosum* Stock, 1952 (Amphipoda, Corophiidae). Ph. D. Thesis, Univ. Aveiro, Portugal.

Elliott, M. & Dewailly, F. 1995. The structure and components of European estuarine fish assemblages. *Neth. J. Aquac. Ecol*., 29 (3-4): 397-417.

Fernandez-Delgado, C.; Hernando, J.A.; Herrera, M. & Bellido, M. 1988. Life history patterns of the sand smelt *Atherina boyeri* Risso 1810 in the estuary of the Guadalquivir River, Spain. *Estuar. Coast. Shelf Sci*., 27: 697-706.

Ferrari, I.; Rossi, R. 1984. Regime alimentare di *Atherina boyeri* Risso in una laguna del Delta del Po. *Nova Thalassia,* 6: 275-280.

Focant, B.; Rosecchi, E. & Crivelli, A.J. 1999. Attempt at biochemical characterization of sand smelt *Atherina boyeri* Risso, 1810 (Pisces, Atherinidae) populations from the Camargue (Rhône delta, France). *Comp. Biochem. Physiol*., 122: 261-267.

Garcia, M.L. 1994. Feeding habits on *Odontesthes smitti* (Atherinidae, fishes) in the South Atlantic. *Vie Milieu*, 44 (2): 151-156.

Gröhsler, T. 1994. Feeding habits as indicators of ecological niches: investigations of Antartic fish conducted near Elephant Island in late autumn/winter 1986. *Arch. Fish Mar. Res*., 42 (1): 17-34.

Hall, S.J.; Raffaelli, D.; Basfors, D.J.; Robertson, M.R. & Fryer, R. 1990. The feeding relationships of the larger fish species in a Scottish sea loch. *J. Fish Biol*., 37: 775-791.

Hayward, P.J. & Ryland, J.S. 1998. *Handbook of the Marine Fauna of north west*. Oxford University press, United States.

Hurlbert, S.H. 1978. The measurement of niche overlap and some relatives. *Ecology*, 59: 67-77.

Hyslop, E.J. 1980. Stomach contents analyses – a review of the methods and their application. *J. Fish Biol*., 17: 411-429.

Kara, M.H. & Derbal, F. 1996. Régime alimentaire du Loup *Dicentrarchus labrax* (Poisson, Moronidé) du Golfe d'Annaba, Algérie. *Annales de l'Institut Océanographique*, 72 (2): 185-194.

Kislalioglu, M. & Gibson, R.N. 1977. The feeding relationship of shallow water fishes in a Scottish sea loch. *J. Fish Biol.*, 11: 257-266.

Krebs, C.J. 1989. *Ecological Methodology*. Harper Row, New York.

Ktari, M.H.; Bou Ain, A. & Quignard, J.P. 1978. Régime alimentaire des Loupes (Poissons, Teleósteens, Serranidae) *Dicentrarchus labrax* (Linné, 1778) et *Dicentrarchus punctatus* (Bloch, 1892) des côtes tunisiennes. *Bull. Inst. Nat. Scient. Tech. Oceánogr.,* 5 (1-4): 5-15.

Labropoulou, M. & Eleftheriou, A. 1997. The foraging ecology of two pairs of congeneric demersal fish species: importance of morphological characteristics in prey selection. *J. Fish Biol.*, 50: 324-340.

Langton, R.J. 1982. Diet overlap between Atlantic cod, *Gadus morhua*, silver hake, *Merluccius bilinearis* and fifteen other northwest Atlantic finfish. *Fishery Bulletin*, 80: 745-759.

Lens, S. 1986. Alimentación del pejerrey, *Atherina presbyter* Cuvier, en la Ría de Arosa. *Bol. Inst. Esp. Oceanogr.*, 3 (2): 11-36.

Leonardos, I. & Sinis, A. 2000. Age, growth and mortality of *Atherina boyeri* Risso, 1810 (Pisces: Atherinidae) in the Mesolongi and Etolikon lagoons (W Greece). *Fish. Res.*, 45: 81-91.

Leonardos, I.D. 2001. Ecology and exploitation pattern of a landlocked population of sand smelt, *Atherina boyeri* (Risso 1810), in Trichonis Lake (western Greece). *J. Appl. Ichthyol.*, 17: 1-5.

Leonardos, J.; Petridis, D. & Kokkinidou, A. 1993. Population dynamics of *Atherina boyeri* (Risso 1810) in the Trichonis lake (W Greece).). In: Proceedings of Sixth Panhel. Symp. Ichthyol., Athens, Greece: 1-19 p.

Lorenzo, J.M. & Pajuelo, J.G. 1999. Age and growth of the Sand Smelt *Atherina (Hepsetia) presbyter* Cuvier, 1829 in the Canary Islands (central-east Atlantic). *Fish. Res.*, 41: 177-182.

Lucas, M.F.; Caldeira, M.T.; Hall, A.; Duarte, A.C. & Lima, C. 1986. Distribution of mercury in the sediments and fishes of the lagoon of Aveiro, Portugal. *Water Sci. Technol.*, 18: 141-148.

Marfin, J.-P., 1982. Les problemes lies au polymorphisme de l'espece *Atherina boyeri* Risso, 1810. *Cybium*, 6 (4): 19-26.

Marshall, N.B. 1971. *Explorations in the life of fishes*. Univ. Press, Harvard.

Marshall, S. & Elliott, M. 1997. A comparison of univariate and multivariate numerical and graphical techniques for determining inter- and intraspecific feeding relationships in estuarine fish. *J. Fish Biol.*, 51: 526-545.

Maugé, L.A. 1990. Atherinidae. In: Quero, J.C.; Hureau, J.C.; Karrer, C.; Post, A. & Saldanha, L. (Eds.), *Check List of the Fishes of the Eastern Tropical Atlantic.* Clofeta II, UNESCO. Paris. 604-605 p.

Mirto, S.; Sciliopoti, D.; Lopiano, L.; Badalamenti, F. & Mazzola, A. 1994. Primi dati sul ritmo alimentare giornaliero di tre specie ittiche nello stagnone di Marsala (Sicilia Occidentale). *Biol. Mar. Mediterr.,* 1 (1): 335-336.

Moreno, T. & Castro, J.J. 1995. Community structure of the juvenile of coastal pelagic fish species in the Canary Islands waters. *Sci. Mar.*, 59 (3-4): 405-413.

Morgado, F.M.R. 1997. Ecologia da zooplâncton da Ria de Aveiro - caracterização espácio-temporal, transporte longitudinal e dinâmica tidal, nictemeral e lunar. Ph.D. Thesis, Univ. Aveiro, Portugal.

Nikolsky, G.V. 1963. *The ecology of fishes*. WB Saunders Company, Philadelphia.

Pajuelo, J.G. & Lorenzom, J.M. 2000. Biology of sand smelt, *Atherina presbyter* (Teleostei: Atherinidae), off the Canary Islands (central-east Atlantic). *Environ. Biol. Fish.*, 59: 91-97.

Pombo, L.; Borges, R.; Rebelo, J.E.; Duarte, A.C. & Bóia, C. 2000. Níveis de mercúrio no músculo de peixes (especialmente robalo, *Dicentrarchus labrax*, LINNAEUS, 1758) capturados no meio natural e em pisciculturas da Ria de Aveiro. Estudos de Biogeoquímica na Zona Costeira Ibérica. In: IX Seminário Ibérico de Química Marinha, Aveiro: 251-259 p.

Pombo, L.; Dias, C. & Rebelo, J.E. 2002 a. Diet comparison between *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal. *Rev. Biol. (Lisboa*), 20: 59-72.

Pombo, L.; Elliott, M. & Rebelo, J.E. 2002 b. Changes in the fish fauna of the Ria de Aveiro estuarine lagoon (Portugal) during the twentieth century. *J. Fish Biol.*, 61 (Supplement A): 167-181.

Pombo, L.; Lopes, C. & Rebelo, J.E. 2002 c. A comparison study on the age and growth of *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal. *Rev. Biol. (Lisboa*), 20: 47-58.

Pombo, L. & Rebelo, J.E. 2000. Ria de Aveiro ictiofauna: diversity in space and time. *Rev. Biol. (Lisboa*), 18: 69-81

Pombo, L. & Rebelo, J.E. 2002. Spatial and temporal organisation of a coastal lagoon fish community, Ria de Aveiro, Portugal. *Cybium*, 26 (3): 185-196.

Quignard, J.P. & Pras, A. 1986. Atherinidae In: Whitehead, P.J.P.; Bauchot, M.L.; Hureau, J,-C.; Nielsen, J. & Tortonese, E. (Eds.), *Fishes of the North-eastern Atlantic and the Mediterranean*, UNESCO. Paris. 1207-1210 p.

Rebelo, J.E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries*, 15 (3): 403-415.

Rosecchi, E. & Crivelli, A.J. 1992. Study of a sand smelt (*Atherina boyeri* Risso 1810) population reproducing in fresh water. *Ecol. Freshwat. Fish.*, 1 (2): 77-85.

Rosecchi, E. & Crivelli, A.J. 1995. Sand smelt (*Atherina boyeri*) migration within the waters system of the Camargue, southern France. *Hydrobiologia*, 300/301: 289-298.

Rosecchi, E. & Nouaze, Y. 1985. Comparaison de cinq indices alimentaires utilisés dans l'analyse des contenus stomacaux. *Ver. Trav. Inst. Pêches Mant.*, 49 (3, 4): 111-123.

Schultz, L.P. 1948. A revision of six subfamilies of Atherine fishes, with description of new genera and species. *Proc. U.S. Nat. Mus.*, 98: 1-48.

Sokal, R.R. & Rohlf, F.J. 1995. *Biometry*. W.H.Freeman and company, New York.

Tomasini, J.A.; Collart, D. & Quignard, J.P. 1996. Female reproductive biology of the sand smelt in brackish lagoons of southern France. J Fish Biol 49: 594-612

Trabelsi, M.; Quignard, J.-P. & Kartas, F. 1994. *Atherina boyeri*: first mention of two sympatric populations in the Mediterranean Sea. Cybium 18 (4): 457-459

Turnpenny, A.W.H.; Bamber, R.N. & Henderson, P.A. 1981. Biology of the sand-smelt (*Atherina presbyter* Valenciennes) around Fawley power station. *J. Fish Biol.*, 18: 417-427.

Valente, A.C.N. 1992. *A alimentação natural dos peixes (métodos de estudo).* Instituto de Zoologia Dr. Augusto Nobre, Univ. Porto, Porto.

Vasil'eva, E.D. 1994. Skull morphology in atherines from the Black Azov and Caspian Seas and some systematic problems of the genus *Atherina* (Atherinidae). *Vopr. Ikhtiol.*, 34 (5): 611-621.

Xie, S.; Cui, Y.; Zhang, T. & Li, Z. 2000. Seasonal patterns in feeding ecology of three small fishes in the Biandantang Lake, China. *J. Fish Biol.*, 57: 867-880.

Zar, J.H. 1984. *Biostatistical Analysis*. Prentice-Hall, New Jersey.

Discussion

Fish behaviour is controlled by internal genetic factors and external environmental factors. Having a good knowledge of the behavioural ecology of the species being study enables the fish researcher to make predictive statements about the environment and the influence it may have on the availability and distribution of fish (Hayes *et al*., 1996).

The distribution and abundance of fishes of Ria de Aveiro are determined by both biotic and abiotic factors. Although these factors are depicted as being independent of one another, in reality there is interaction between a number of them and the fishes which inhabit in the lagoon. Attempts to focus on only the biotic (food resource) or the abiotic components of habitat would provide an inadequate and inaccurate view of the relationship of the environment to fish production (Hayes *et al*., 1996).

Having examined some of the factors affecting the ichthyofaunal diversity and abundance in the Ria de Aveiro, and arrived at the conclusion that this system has for various reasons a relatively low species diversity, it is necessary to address the question as to whether the efficient utilisation of estuarine food resources depend on the species diversity of the fish community.

For the Ria de Aveiro, it is clear that changes in environment appear to have greater effect on fish distribution than do biological interactions. That result shows that changes in food resources are not predictable from estimated changes in fish distribution. Nevertheless, analyses of resource utilisation are essential in the studies of fish ecology, with successful coexistence relying heavily upon differential resource use. Many of the behaviour patterns and morphological adaptations of fish species have evolved in relation to the capture of food and the avoidance of capture/predation. The mechanisms employed by fish for feeding represent adaptations which enable them to take advantage of particular types of prey (Alexander, 1974; Elliott & Hemingway, 2002).

Ten fish species were found to be abundant in the Ria de Aveiro, this includes two species of each ecological guild and these species represent the major feeding categories.

Detritus seemed to be the most important food source for many fish species in the lagoon in addition to small benthic crustaceans, annelids or molluscs. Detritus in estuaries consists of a mixture of plant debris and amorphous organic matter together with associated heterotrophic and autotrophic micro-organisms (Bowen, 1976). Detritivorous fish taxa are well represented in the Ria de Aveiro, despite the often higher species diversity of carnivorous fishes; the former group are normally dominant in terms of biomass, such as the mullets (*Liza aurata*, *L. ramada* and *L. saliens*). Research in northern hemisphere estuaries has shown that the transfer of energy to fishes centres on the detrital food web (Odum, 1971; Elliott & Hemingway, 2002) and studies in southern African systems reinforce this concept (Whitfield, 1988). Elliott & Hemingway (2002) indicate the central role of detritivorous small crustaceans in the fish-dominated foodwebs in estuaries.

Phytoplankton productivity in estuaries, in general, is highly variable (Campbell *et al*., 1991) and this may account for the absence of phytoplanktivorous fish species from these systems. Zooplankton, which feed extensively on phytoplankton, are sometimes present in large numbers in estuaries and are an important food source for planktivorous fish species within these systems (Blaber, 1979). However, phytoplankton biomass varies both spatially and seasonally whereas an abundance of detritus is available to estuarine consumers, including zooplankton and iliophagous fish species, throughout the year (Whitfield, 1980). It would appear, therefore, that the detritus food web confers stability to estuarine ecosystems by making the energy fixed seasonally by primary producers available to consumers throughout the year (Whitfield, 1996). True phytoplankton in estuaries is poorly represented due to the high turbidity and so microscopic algae in the water column are often resuspended microphytobenthos; hence zooplankton which make be herbivores feeding on phytoplankton in the open sea, are often detritivores feeding on freeliving and attached bacteria in estuaries (McLusky & Elliott, 2004).

The prey selection by fishes is governed, in part, by their ability to detect and locate prey. Vulnerability to a predator often depends on the relative sizes of predator and prey. Within the range of prey sizes that are vulnerable, prey

selection by the predator may be driven by prey profitability, the net energy gained per unit of handling time required (Rice *et al*., 1993).

Thus, the morphological differences between fish species and therefore differences in feeding mechanisms and the corresponding foraging modes allow sympatric species to coexist by minimising or avoiding interspecific competition (Labropoulou & Papadopoulou-Smith, 1999).

Very little information is available on competition for food resources by fishes within the Ria de Aveiro estuarine lagoon. Most carnivorous fish species feed on a wide range of prey and can adjust their diet according to environmental conditions and food availability (Marais, 1984; Hecht & van der Lingen, 1992).

The notion that competition is important in the ecology of organisms, from the organism to the community level, has become a cornerstone of ecological and evolutionary theory (Pusey & Bradshaw, 1996). Typically, the intensity of competition has been analysed by estimating some measure of the similarity or overlap in resource used by sympatric taxa, but it is also necessary to have information on the abundance and diversity of available resources. Otherwise, high overlap may, paradoxically, be evidence for either the presence of competition or its absence (Pusey & Bradshaw, 1996).

The most successful fish species in estuaries were those with the broadest niches and, *inter alia*, widest tolerance, and specialisation seemed to be a dubious means of reducing competition, i.e., if a fish is very specialised in one species the competition will be high when other fish feed on the same prey. There appears to be an even greater overlap in the diets of detritivorous fish species from Ria de Aveiro, with competition being reduced by different mechanisms which result in the available food items being consumed in different quantities (Whitfield & Blaber, 1978). However, within Mugilids and also Atherinids there appears to be little feeding segregation between species (Blaber, 1976, 1977) with seasonal separation of estuarine use or, in the later case, with a strong selective spatial distribution with the age.

Seasonal migrating species and marine adventitious species exert a variable pressure on food resources throughout the year, depending on stability and coupling between environmental and biological factors, such as water

temperature, quality and availability of food, etc. (Margalef, 1982). These factors describe cycles more or less variable yearly and they determine delays or extensions of spawning periods, growth ranges (Lemm *et al*., 1993) and even migrations between areas (Laevastu & Larkins, 1981). Furthermore, it is nor possible to define trophic levels due to the fact that most of the fish species change their diet composition throughout their life cycle, the seasons of the year and the different growth areas. These changes are related to the spatial and temporal variations in food composition and available food resources (Laevastu & Larkins, 1981; Bowen, 1985).

The use of the estuarine lagoons by juvenile fish in the Ria de Aveiro could be classified as primary (based on detritus and zooplankton), and strongly dependent on environmental conditions.

The general strategy of occupation of pelagic fish is based on high densities of individuals of the same species, as in the case of *Sardina pilchardus* or *A. boyeri* compared to *A. presbyter*. This strategy could reduce interspecific competition by spatial exclusion of other species (Moreno & Castro, 1995).

The utilisation of the coastal ecosystem during different periods of time (time-sharing, temporal resource partitioning cf. spatial resource partitioning) is another strategy that reduces competition between species for food resources. *Dicentrarchus labrax* remains in this ecosystem only during its early juvenile stages (Rebelo, 1993). When the lagoon ecosystem starts to be depleted, and the species are ready to migrate to the sea, they change significantly their trophic strategy. At this time specimens reached 17-23 cm total length (Rebelo, 1993).

Some other species show a trophic specialisation to reduce competition with strictly zooplanktivorous species. This fact confers more stability on their populations (Weatherley & Gill, 1987). This specialisation could be restricted to a determined stage and it is directly influenced by the presence of a specific food resource (Laevastu & Larkins, 1981). This strategy is observed on *Symphodus bailloni*, which lives mainly close to the mouth of the lagoon and in the main channel and its diet clearly depends on small benthic crustaceans, as amphipods and isopds, dominant in these areas (Cunha, 1999).

The present study has shown that juveniles of pelagic fish species that grow in estuarine coastal lagoons show different strategies of use of space and food resources. The above described strategies must not be strictly considered for all parts of life cycles, because they could be restricted to a specific stage. The combination of different strategies gives a wider spectrum of the possibilities of exploitation of the limited carrying capacity of the coastal lagoons, thus reducing interspecific competition (Moreno & Castro, 1995). i.e. species which have wide tolerances and a wide degree of feeding strategies will be more successful in estuarine habitats.

While intraspecific comparisons according to size are possible for only some of the species, in this study, interspecific interactions were assessed in greater detail. It can be seen that *S. pilchardus*, mullets (*L. aurata*, *L. ramada* and *L. saliens*) and *Pomatoschistus microps* have overlapping spatial distributions, as well as showing dietary similarity, indicating the possibility of high level of competition. However, as seasonal differences in the distributions of sardine, with positive relationships with temperature and salinity, and mullets with negative relationships with temperature and salinity, are illustrated that potential competition may be avoided by the seasonal separation of estuaries usage.

Other species with dietary similarities, i.e, sea bass and eel, show little overlapping in their distributions, suggesting that food availability may not limit these populations. However, more information is required on the availability of prey organisms and the spatial and temporal feeding habits of the different species, the importance of which has been demonstrated in other areas (Tyler, 1972; Marshall & Elliott, 1996; Elliott & Hemingway, 2002).

Finally, atherinids have special attention in this chapter, not only in the feeding aspects but also ecology, age and growth.

A comparison of diet breadth reflects the generalised feeding strategy for both species, being higher for *A. presbyter*, whose diet tends to a specialization on some prey/food type such as detritus and microcrustaceans, and also on a high variety of rare prey, as macrocrustaceans, leading to a more mixed feeding strategy compared to *A. boyeri*.

As *A. presbyter* grows faster than *A. boyeri,* its gape length allows them to consume bigger prey, when they are available in the environment. Fernandez-Delgado *et al*. (1988), Creech (1992), and Leonardos & Sinis (2000) showed that fish length composition was markedly different in both species: *A. presbyter* was bigger but thinner and its growth was faster and higher than *A. boyeri*, which may be related to its food preference for big prey.

Both species showed differences in diet between different size classes suggesting that some resource partitioning occurs. However, fish appeared to have different distribution areas with the age.

It was also noted that their diet was dependent on species availability, rather than preference or selection. However, there is evidence from the present study that *A. presbyter* is size-selective since it exploited the largest prey comparing to *A. boyeri*. Thus, it could be assumed that *A. presbyter* actively searches for its prey and avoids species of unsuitable size.

In summary, both species are considered to be sympatric species as they might occur at the same space and in the same time. Furthermore, on the basis of morphoanatomical parameters, the sand smelt species is viewed as a highly polymorphic complex (Marfin, 1982; Kartas & Trabelsi, 1990; Focant *et al*., 1992, 1999; Klossa-Kilia *et al*., 2002; Trabelsi *et al*., 2002a and b). This is further evidence for the value of assessing fish communities based on functional guilds rather than just taxonomic identities.

Thus, further studies on biometric, biochemical and genetic investigations in the lagoon will be needed to interpret these features further. Using the tools that were available for this study, and being conscious of some limitations of the methods, this study allowed the distinguishing of ecological behaviour and biological characteristics between the species. The abundance and distribution per space and time by length and age, the abiotic preference during the lifespan, the fish and otolith length-weight relationships and the age and growth parameters were markedly distinct in both species.

Although the species studied here in detail are spatially and temporally sympatric, the dietary overlap, found only on older individuals, suggests that food

resources are well partitioned for these coexisting species and thus interspecific and intraspecific competition is minimal. Most studies of niche partitioning among sympatric fish species show that trophic separation is the major axis in which partitioning occurs (Ross, 1986). Hence the results here suggest that each species follows a different pattern in order to maximize the energy intake. It may be hypothesised that prey abundance in an organically rich estuary is less important as a mechanism to structure the fish assemblage than are environmental factors (Thiel *et al*., 1995; Marshall & Elliott, 1996).

References

Alexander, R. McN. 1974. *Functional Design in Fishes*. Hutchinson, London.

Bagenal, T.B. 1978. *Methods for Assessment of Fish Production in Fresh Waters*, 3rd edn. Blackwell, Oxford.

Blaber, S.J.M. 1976. The food and feeding ecology of Mugilidae in the St Lucia lake system. *Biol. J. Linn. Soc., 8*: 267-277.

Blaber, S.J.M. 1977. The feeding ecology and relative abundance of mullet (Mugilidae) in Natal and Pondoland estuaries. *Biol. J. Linn. Soc., 9*: 259-275.

Blaber, S.J.M. 1979. The biology of filter feeding teleosts in Lake St Lucia, Zululand. *J. Fish Biol.*, 15: 37-59.

Bowen, S.H. 1976. Mechanisms for digestion of detrital bactteria by the cichlid fish Sarotherodon mossambicus (Peters). *Nature*, 260: 137-138.

Bowen, S.H. 1985. Quantitative description of the diet. In: Nielsen, L.A. & Johnson, D.L. (Eds.) *Fisheries Techniques*. Am. Fish. Soc. Virginia. 468p.

Campbell, E.E.; Knoop, W.T. & Gate, G.C. 1991. A comparison of phytoplankton biomass and primary production in three Eastern Cape estuaries, South Africa. *S. Afr. J. Sci.*, 87: 259-264.

Creech, S. 1992. A multivariate morphometric investigation of *Atherina boyeri* Risso, 1810 and *A presbyter* Cuvier, 1829 (Teleostei: Atherinidae): morphometric evidence in support of the two species. *J. Fish Biol.*, 41: 341-353.

Cunha, M.M.P.R. 1999. Peracaridan crustacea in Ria de Aveiro (NW Portugal): taxonomic composition and spatio-temporal structure of the assemblages; life history and secondary production of *Corophium multisetosum* Stock, 1952 (Amphipoda, Corophiidae). Ph.D. Thesis, University of Aveiro.

Elliott, M. & Hemingway, K.L. (Eds.). 2002. *Fishes in Estuaries*. Blackwell Science, Oxford.

Fernandez-Delgado, C.; Hernando, J.A.; Herrera, M.; Bellido, M. 1988. Life history patterns of the sand smelt *Atherina boyeri* Risso 1810 in the estuary of the Guadalquivir River, Spain. *Estuar. Coast. Shelf Sci.*, 27: 697-706.

Focant, B.; Rosecchi, E. & Crivelli, A.J. 1999. Attempt at biochemical characterization of sand smelt *Atherina boyeri* Risso, 1810 (Pisces, Atherinidae) populations from the Camargue (Rhône delta, France). *Comp. Biochem. Physiol.*, 122: 261-267.

Focant, B.; Trabelsi, M.; Kartas, F.; Quignard, J.-P. 1992. Charactérization biochemique de trois populations d'*Atherina boyeri* des milieux lagunaires méditerranéens. *Rapp. Comm. Int. Mar. Medit.*, 33: 80- 94.

Gill, A.B. & Hart, P. 1996. Unequal competition between three-spined stickleback, *Gasterosteus aculeatus*, L., encountering sequential prey. *Anim. Behav*., 51: 689-698.

Hayes, D.B.; Ferreri, C.P. & Taylor, W.W. 1996. Linking fish habitat to their population dynamics. *Can.J.Fish.Aquat.Sci*., 53 (Suppl. 1): 383-390.

Hecht, T. & Van Der Lingen, C.D. 1992. Turbidity-induced changes in feeding strategies of fish in estuaries. *S. Afr. J. Zool.*, 27: 95-107.

Homer, M.; Mihursky, J.A. & Jones, P. 1981. In: Schaefer, R.H. (Ed.), Proceedings of the 4th Ann.Mtg.Amer. Soc., Potomac chapter. 1-43 p.

Hyslop, E.J. 1980. Stomach contents analyses – a review of the methods and their application. *J. Fish Biol.*, 17: 411-429.

Kartas, F. & Trabelsi, M. 1990. Sur le polymorphisme de l'Athérine, *Atherina boyeri* Risso 1810 (Atherinidae) des eaux littorales tunisiennes. *Cybium*, 14: 295-311.

Klossa-Kilia, E.; Prassa, M.; Papasotiropoulos, V.; Alahiotis, S. & Kilias, G. 2002. Mitochondrial DNA diversity in *Atherina boyeri* populations as determined by RFLP analysis of three mtDNA segments. *Heredity*, 89: 363-370.

Labropoulou, M. & Papadopoulou-Smith, K.-N. 1999. Foraging behaviour patterns of four sympatric demersal fishes. *Estuar., Coast. Shelf Sci.*, 49 (Supplement A): 99-108.

Laevastu, T. & Larkins, H.A. 1981. *Marine Fisheries Ecosystems. Its quantitative evaluation and management.* Fishing News Books Ltd.

Lemm, C.A.; Herman, R.L.; Lemario, D.P. & Arzapalo, A. 1993. Effects of diet and environmental salinity on the growth, mortality and tissue structure of juvenile striped bass. *J. Aquat. Health*, 5: 294-305.

Leonardos, I. & Sinis, A. 2000. Age, growth and mortality of *Atherina boyeri* Risso, 1810 (Pisces: Atherinidae) in the Mesolongi and Etolikon lagoons (W Greece). *Fish. Res.*, 45: 81-91.

Marais, J.F.K. 1984. Feeding ecology of major carnivorous fish from four Eastern Cape estuaries. *S. Afr. J. Zool.*, 19: 210-223.

Marfin, J.-P. 1982. Les problèmes lies au polymorphisme de l'espèce *Atherina boyeri* Risso, 1810. *Cybium*, 6 (4): 19-26.

Margalef, R. 1982. *Ecología.* Ediciones Omega, S.A., Barcelona.

Marshall, S. & Elliott, M. 1996. The structure of the fish assemblage in the Humber Estuary, U.K. *Publ. Espec. Inst. Esp. Oceanogr.,* 21: 231-242.

Marshall, S. & Elliott, M. 1997. A comparison of univariate and multivariate numerical and graphical techniques for determining inter- and intraspecific feeding relationships in estuarine fish. *J. Fish Biol*., 51: 526-545.

McLusky, D. & Elliott, M. 2004. *The Estuarine Ecosystem: ecology, threats and management*, 3rd Ed. OUP, Oxford.

Moreno, T. & Castro, J.J. 1995. Community structure of the juvenile of coastal pelagic fish species in the Canary Island waters. *Sci. Mar.*, 59 (3-4): 405-413.

Odum, W.E. 1971. *Fundaments of Ecology.* W.B. Saunders, Philadelphia.

Pauly, D. 1980. *A selection of Simple Methods for the Assessment of Tropical Fish Stocks.* FAO Fisheries Dept., Rome.

Pavlov, D.S. & Kasumyan, A.O. 1998. The structure of the feeding behavior of fishes. *J. Ichthyol.,* 38 (1): 116-128.

Pombo, L.; Lopes, C. & Rebelo, J.E. 2002. A comparison study on the age and growth of *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal. *Rev. Biol. (Lisboa)*, 20: 47-58.

Pusey, B.J. & Bradshaw, S.D. 1996. Diet and dietary overlap in fishes of temporary waters of southwestern Australia. *Ecol. Freshwat. Fish.*, 5: 183-194.

Rebelo, J.E. 1993. A Ictiofauna da Ria de Aveiro e o período lagunar do ciclo de vida do robalo, *Dicentrarchus labrax* LINNAEUS, 1758. Ph.D. Thesis, University of Aveiro.

Rice, J.A.; Crowder, L.B. & Rose, K.A. 1993. Interactions between size-structured predation and prey populations: experimental test and model comparisons. *Trans. Am. Fish. Soc.*, 122: 481-491.

Ross, S.T. 1986. Resource partitioning in fish assemblages: a review of field studies. *Copeia*, 2: 352-388.

Shuter, B.J. 1990. Population-level indicators of stress. *Am. Fish. Soc. Symp.*, 8: 145-166.

Thiel, R.; Sepulveda, A.; Kageman, R. & Nellen, W. 1995. Environmental factors as forces structuring the fish community of the Elbe estuary. *J. Fish Biol.*, 46:47-69.

Trabelsi, M.; Faure, E.; Quignard, J.-P.; Boussaïd, M.; Focant, B. & Mâamouri, F. 2002 a. *Atherina punctata* and *Atherina lagunae* (Pisces, Atherinidae), new species in the Mediterranean Sea. 1. Biometric investigations of three Atherinid species. *R.C. Biologies*, 1-9.

Trabelsi, M.; Gilles, A.; Fleury, C.; Mâamouri, F.; Quignard, J.-P. & Faure, E., 2002 b. *Atherina punctata* and *Atherina lagunae* (Pisces, Atherinidae), new species in the Mediterranean Sea. 2. Molecular investigations of three Atherinid species. *R.C. Biologies*, 1-10.

Tyler, A.V. 1972. Food resource division among northern marine, demersal fishes. *J. Fish Res. Board Can.*, 29: 997-1003.

Weatherley , A.H. & Gill, H.S. 1987. *The biology of fish growth.* Academic Press, London.

Whitfield, A.K. & Blaber, S.J.M. 1978. Resource segregation among iliophagus fish in Lake St Lucia, Zululand. *Environ. Biol. Fish.*, 3: 293-296.

Whitfield, A.K. 1980. A quantitative study of the trophic relationships within the fish community of the Mhlanga estuary, South Africa. *Estuar. Coast. Mar. Sci.*, 10: 417-435.

Whitfield, A.K. 1988. The fish community of the Swartvlei estuary and the influence of food availability on resource utilization. *Estuaries*, 11: 160-170.

Whitfield, A.K. 1996. A review of factors influencing fish utilization of South African Estuaries. *Trans. Roy. Soc. S. Afr.* 51: 115-137.

Wootton, R.J. 1990. *Ecology of Teleost Fishes*. Chapman and Hall, New York.

CHAPTER III – Assessment of Fish Production Capacity

Introduction

Estuaries as a habitat rank along with tropical rain forests and coral reefs are highly productive ecosystems (Costanza *et al.*, 1997). According to Correll (1978) the high primary productivity of these systems is maintained because of high nutrient levels in the bottom sediments and water column. The abundant fish stocks associated with estuaries are probably linked to the exceptional primary and secondary productivity within these systems (Whitfield *et al*., 1994; Grange *et al*., 1995; McLusky & Elliott, 2004).

The key to the attractiveness of estuarine systems to fishes therefore lies in the fact that they act as detritus traps, providing abundant food resources for filter and deposit-feeding invertebrate prey. Visual evidence of this process can be seen in estuaries where marine macroalgal material accumulates in the upper and middle reaches, and littoral plants such as mangroves, salt marsh grasses and reeds accumulate mats of decomposing riverine and estuarine plant material around their stems and roots (Whitfield, 1996). In this way the loss of potential estuarine macrodetritus to the sea is reduced. Elliott & Hemingway (2002) also emphasise that estuaries are widely recognised to have a high productivity, however, material produced within the estuary itself (autochthonous material) or that exported into the estuary (allochthonous material) would have little effect on the biota if they are not retained in the estuary.

Research in northern hemisphere estuaries has shown that the transfer of energy to fishes centres around the detrital food web (Odum, 1971; Elliott & Hemingway, 2002) and studies in southern African systems reinforce this concept (Whitfield, 1988).

Production is defined as the total elaboration of new body substance (biomass) in a stock during a unit time, irrespective of whether or nor it survives to the end of that time (Ricker, 1971). Production depends on the time interval over which it is measured, the presence or absence of predators, and the growth and natural death rate of population. The combination of these factors is very difficult to measure in estuaries which are always changing by tides and river flows and on species which have a rapid growth, which migrate according to age and hydrological conditions and whose recruitment is composed of several temporal

pulses or a continuous immigration (Elliott & Hemingway, 2002), and consequently production estimates are only approximate.

Fish production is, however, the best indicator of the quantitative performance of a fish population in any type of habitat, and it is a measure of productive capacity (Jones *et al*., 1996; Minns *et al*., 1996). However, estimation of production in the field is time consuming and costly, and often, surrogates of production are used to evaluate habitat suitability or capacity. For any defined time period, fish production is the product of average biomass and specific growth rate, and therefore, fish biomass and fish production are correlated (Randall *et al*., 1995). The ratio of these $P/\overline{B}$ indicates the nature of the functioning of the system; this ratio is also termed productivity.

Specific or population production varies with fish size, so it is important to estimate the fish production by cohorts. As the size of individuals increases over a year, specific production considered in this paper is based on two years time to compare the results. Other parameters are also important to consider such as the variability of the climate if considering interannual comparisons (as we did during two subsequent years), variations in food availability, mortality by diseases, by predation and by fishing, as over-fishing of target species or by-catch. So, it is not surprising that few data exist on fish production and the level of knowledge about the food web structure and production of important species of the lagoon is preliminary, but also a valid, indeed essential, for support the habitat questions.

Many management practices with regard to estuarine fisheries have not as yet advanced much, part of the problem is of a political nature but a major source of management inadequacies has been the lack of data regarding quantitative estimates of estuarine fish stocks and quantitative trophic relationships (Homer *et al*., 1980). The other problem with production analysis may be the fishery production of the commercial species. Given the nature of fishing, commercial landings and recordings, yields (i.e. socio-economical data and mainly based on official statistical reports) which therefore do not exactly match the true value of catch (Elliott & Hemingway, 2002), however give a general idea that could be comparable with the fish production estimates.

Fisheries thus have a potentially large ecological impact through the killing of target species. These species are normally very abundant on their trophic level. Thus, fisheries must be managed to avoid unacceptable ecological effects and not primarily to optimise catches. One problem in this is that non-biologists often do not have the necessary ecological understanding of the concepts required for a constructive dialog between fisheries managers and ecologists (Hansson, 1999).

The fish catches are important in an ecosystem context (Blaber *et al.,* 2000) especially if the killed fish are ecologically important and their mortality is significantly increased by the fishery. Most of the target species are naturally very abundant, and they are hence important ecosystems components. A consequence of this is that the fishery is likely to influence not only the target species, but indirectly also many other organisms that ecologically are related to them.

Blaber *et al*. (2000) emphasises that fishing in the estuaries has clear impacts on the structure and functioning of these ecosystems, although other, non-fishing issues also affect these ecosystems. This creates multiple interactions and reinforces the need for an integrated approach to coastal zone management.

The implementation of an ecosystem management approach requires a close cooperation between traditional fisheries managers, fish ecologists and general marine ecologists/biologists. In a democracy, the general environmental goals for the management must also be politically and socially determined. Therefore it is important for society to determine whether an estuarine environment should be manipulated to maximise fisheries. First, it is important to ensure long-term sustainability and equity in sharing of the fish resource. For that, the better knowledge of the estuarine in question is the key for a more adequate and more appropriate management of the system.

In estuaries, the open interactions with the sea are important because processes at the littoral area account for most estuarine productivity and is most strongly affected by conditions in adjacent habitats (Whitfield, 1996). The coastal zone also serves as critical habitat for various life stages of most fish and that habitat changes have serious implications for the estuarine lagoon as a whole.

As shown by the previous sections of this thesis, the Ria de Aveiro contains a great variety of habitats with an unquestionable ecological and economic importance. All the human activity of this region has been strongly marked for the existence of the lagoon. Fishing activities, the aquaculture, the production of salt, the seaweed gathering, the molluscs catching and agriculture are indispensable for the preservation of Ria de Aveiro and for the local economy (*Anon*., 1998).

In terms of aquaculture, all the ecosystems present a strong potential for this activity, assured for its climate maritime and raised insolation (Gonçalves & Sobreiro, 1992).

The species with higher commercial value are sea bass (*Dicentrarchus labrax*), eel (*Anguilla anguilla*), sole (*Solea sp*.), and flounder (*Platichthys flesus*) (Rebelo & Pombo, 2001).

The production of the aquaculture in Portugal has significantly increased in recent years, reaching an annual tax of 20% (1992/95) (Gonçalves & Sobreiro, 1992).

In a country where the annual consumption of fish is about 50kg per capita, and considering that the wild caught fish production has decreased, aquaculture plays an important role in available fish resources. The aquaculture is a restricted sector in fisheries, which production corresponds to about 5% of the captured and discharged wet fish volume in continental waters (Gonçalves & Sobreiro, 1992).

The fishing sector is an essential economic activity in the region, practised in three different aquatic environments: the lagoon, the coastal zone, and the sea. The “Capitania de Aveiro” has under its jurisdiction about 20 ports, of which 15 are located in the lagoonal zone, being the Port of Aveiro one of the most important in a national context (Borrego *et al*., 1994). Fishing and the related activities (the equipment and arts of fishing, the naval industry, the fish commerce, the transformation industries of canned goods and congelation) constitute an important sector in the economy of the Aveiro region.

The fishing activity in the lagoon represents an important source of the net income, essentially for the marginal populations, highly developed near the mouth of the lagoon (Barra) and also in Costa Nova.

In terms of the annual fishing volume, Reis (1993) makes reference that fish captured in Ria de Aveiro was about 2000 ton.year^{-1} in 1956, having decreased for 500 ton.year^{-1} between 1962 and 1977 and for about 400 ton.year^{-1} in 1990.

Despite of a long history of research, little quantitative information about the capacity of fish production exists for this lagoon. The main aim of this chapter was to estimate the fish production within two subsequent years and compare it with the fishing available levels. The comparison can be extended to other temperate estuaries. These features are of high relevance and importance hence the estimates of fish production are necessary in order to predict the sustainability of the lagoon and its resources.

The objectives included intensive monthly sampling with the same type of net and under the same conditions and the somatic production of individual fish was computed by the method of Chapman. The cohorts were determined by the age groups obtained by otoliths and scales readings during each of the two years.

The hypotheses assess the comparison of the somatic production of fish capacity with the fisheries in order to detect whether the system is in equilibrium, or, opposing, if the system will be in risk in the near future.

The Somatic Production of the Fish Community in an Estuarine Coastal Lagoon, Ria de Aveiro (Portugal)

Pombo, L.; Rebelo, J.E. and Elliott, M. 2004.

Presented in the ECSA Local Meeting, 9-10 Sept 2004, Lisbon.

Submitted to Hydrobiologia

The Somatic Production of the Fish Community in an Estuarine Coastal Lagoon, Ria de Aveiro (Portugal)

Abstract

The present study aims to determine biological fish production of a lagoon and relate this to the commercial fisheries yield. The fish community of an estuarine lagoon in the west coast of Portugal was sampled between November 1998 and November 2000 to estimate the production ecology of the community, including somatic production, population size, species richness, species diversity, and biomass. Using the Allen curve method of determination, the total annual fish production of all fish species in the lagoon was calculated at 90.3 tonnes or 2.1 g m^{-2} $year^{-1}$ in the first year and 106.7 tonnes or 2.5 g m^{-2} $year^{-1}$ in the second year. The marine seasonal migrant species, sardine, Sardina pilchardus, which colonizes the lagoon during the juvenile period of its life stages, produced more than 35 tonnes in each year and accounted for > 39% and >33%, in the first and second year respectively, of the total fish production in this lagoon. Sardine was numerically more abundant (18,217 specimens) but due to their small size contributed only 13% to the total biomass. Sardine was thus the most important fish species in terms of the consumption and production processes of the whole fish community in this system. Commercial fisheries records indicate that approximately 300 tonnes per annum of fish are taken from the lagoon, which corresponds to three times more than the estimated production in the lagoon. Thus, if it exists, the sustainability of the fishery appears to depend on the immigration of fish from the adjacent coastal area and it is questioned whether the fishery is sustainable in the long term. The findings indicate that careful and effective management of the lagoon is required to ensure a long-term healthy aquatic environment and sustainable catches in the future.

Keywords: Fish production, estuarine lagoon, Ria de Aveiro.

Introduction

Estuarine habitats are referred to as being 'nutrient traps' that support high primary productivity, which in turn promote high levels of secondary production (Nixon *et al*., 1986; McLusky & Elliott, 2004). Production by fish depends to a great extent on the rate at which food is consumed, and therefore, particular attention is paid to the rates of food consumption of the earlier life stages (Wootton, 1986). In turn, the highest production rates, in terms of somatic production per unit biomass, are achieved by the younger and smaller fishes (larvae and juveniles) (Mahon *et al*., 1979; Morgan, 1980; Elliott & Hemingway, 2002). Hence the estuaries' primary function as nursery and feeding areas for many species make them a productive habitat (Elliott & Hemingway, 2002).

The Ria de Aveiro, as with other estuarine systems in general (Rogers et al., 1984), is believed to have an essential role as spawning and nursery areas for many fish species (Rebelo, 1992; Rebelo & Pombo, 2001; Pombo & Rebelo, 2002). Despite this, compared to freshwater and marine habitats, more studies are required to quantify the nursery function of estuarine waters, their production ecology and the links between biological and fisheries production. However, such studies are limited because of the difficulties of quantifying the abundance and biomass of fish and their potential food organisms in estuaries (Aneer *et al*., 1992); such studies are labour intense, time consuming and often very expensive (Cowley & Whitfield, 2002). Hence prior to the present study, no information existed regarding the somatic production and food consumption by the fish community of the Ria de Aveiro estuarine lagoon. As a first step, since 1912, ichthyological information has been obtained for the Ria de Aveiro (Osório, 1912; Nobre *et al*., 1915; Arruda *et al*., 1988; Rebelo, 1992; Pombo & Rebelo, 2002), and the long-term changes in the fish abundance during the 20th century have been analysed (Pombo *et al*., 2002a). More recently, attention has been drawn to the environmental influence on the fish community (Pombo *et al*., 2003), feeding habits (Pombo *et al.*, 2002b), and aspects of ecology and growth of some abundant species (Pombo *et al*., 2002c). For example, high biomasses of zooplanktivorous and detritivorous fish (Pombo *et al*., 2003) have been found to occur in the

estuarine lagoon together with high densities of copepods (Morgado, 1997; Cunha, 1999). This indicates the habitat preferences of zooplanktivorous and/or detritivorous fish and suggests the importance of trophic parameters as structuring forces of the fish community of Ria de Aveiro.

Estimates of the fish production are highly relevant for understanding ecosystem functioning (Elliott & Hemingway, 2002) and as a precursor to ecosystem (energy budget) modelling. They also allow the predicting of potential yields for fishery species (Cowley & Whitfield, 2002). This is particularly important because of the increased focus on both commercial and recreational fisheries in determining whether the current management regime is adequate to ensure long-term sustainability of the estuarine lagoon.

The main aim of the present study is to estimate the fish community somatic production during two subsequent years and to compare it with data from fisheries harvesting yields to indicate the state of the lagoon. In turn this allows an estimation, for example, of whether the lagoonal fish carrying capacity and biological integrity could be (or not) at risk within this important estuarine lagoon. This paper also compares the obtained estimates with values of others similar ecosystems cited in the literature and determines the relative contributions made by abundant fish within the different ecological guilds (Elliott & Hemingway, 2002).

Study Area

Although the changes to the geomorphology of the Ria de Aveiro (Fig.1) started in the tenth century, the connection with the sea (470 m width) was first stabilized by man in 1808. The Ria is influenced by a maritime, temperate climate which has a well-defined seasonal variation in the air temperature and rainfall. The topography and physical characteristics were described by Barrosa (1980) who indicates an area of 42 km^2 at low tide and 47 km^2 at high tide, tidal action mixes freshwater with seawater entering from the mouth and the tidal input is approximately between 25 and 90x106 m^3 for tidal amplitudes of 1 and 3 m respectively. Currents produced by this tidal action are significant only at the mouth, the central part of the main channels and a few other restricted areas and there is a delay of 6 hours in the times of high and low water between the mouth

and the extreme margins of the lagoon. The nature of the sediments, in particular the granulometry, is extremely variable and varies between 20 to 90% sand, 10 to 80% of silt and 0 to 30% of clay. In the north the sediments are finer but become coarser with progression to the south (Borrego *et al*., 1994).

The depth at low tide is only 1 m over most of the lagoon, but can reach 10 m near the mouth and in the navigation channels. During the investigated period, the water temperature varied between 7.6 ºC in winter and 27 ºC in summer and salinity ranged from typically freshwater (0 psu) to marine water (36 psu). Further details regarding the environmental conditions in the Ria de Aveiro are given in Pombo & Rebelo (2002).

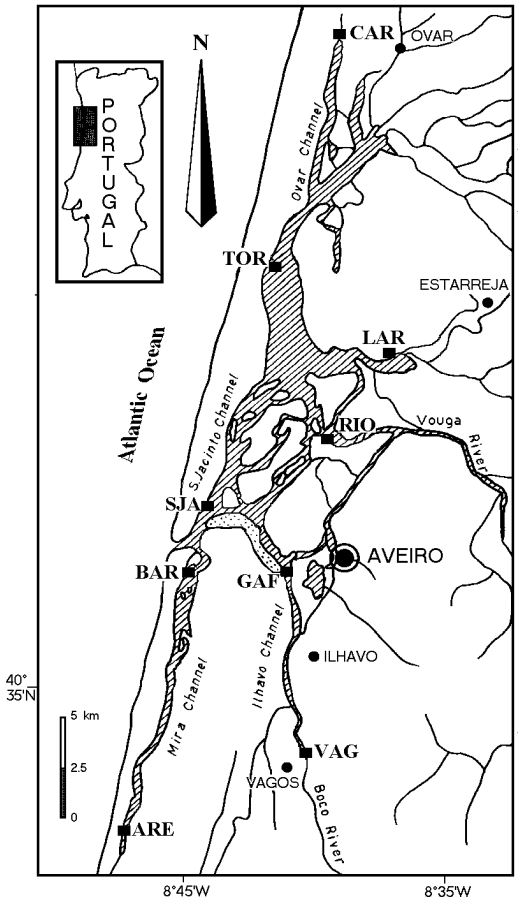

Fig. 1. – Map of the Ria de Aveiro showing the sampling stations.

The area is economically important because of its fisheries, industry, agriculture, sea farming, tourism and, more recently, aquaculture. With a good communication with the sea, seasonal fish recruitment is guaranteed and the lagoon has a considerable fish exploitation (commercial and recreational). Unfortunately, the increasing population density and number of uses of the lagoon has affected the natural system and its integrity (Pombo *et al*., 2002a). Channels have been dredged, marshes and tidal flats in-filled, waters polluted, and shorelines reconstructed to accommodate human housing, transportation and agriculture needs (JAPA, 1993). Because of these anthropogenic impacts, it is increasingly necessary to understand and protect the functioning of the lagoon and its resources.

Material and Methods

Fish Sampling

Fish were monthly sampled, between November 1998 and November 2000, with a “chincha”, a traditional beach-seine net. At each site and month, 3 replicate samples were taken at low tide, during the five days of the new moon at adjacent, non-overlapping areas at nine sites. These sites strategically covered all the lagoon area and are designated as: BAR, GAF and SJA (near the mouth of the lagoon); ARE, CAR and VAG (at the edges of the main channels); RIO (in the main freshwater area, highly organically enriched); LAR (in the area showing the highest levels of industrial pollution) and TOR (approximately in the middle of the longest channel) (Fig. 1). The “chincha” gear used was almost rectangular in shape and composed by a central bag (a ‘cod-end’, 295 cm of length and 145 cm of wide), two lateral wings (12 m of length each, the width decreasing along the net, reaching 50 cm at the edge), two ropes (6.1 m each), and floating buoys at the top and ceramic weights at the bottom of the net. The end of the net was fixed to the margin and the remainder was trawled in a semi-circle thus retaining within the cod-end all the fish from the area. The total area enclosed by the gear was esteemed calculating the area of the semicircle of the lateral wings (93.6 m^2), plus the area of the semi-circle of the cod-end (5.6 m^2), plus the area of the rectangle formed by the two ropes (94.2 m^2). The area of the whole net was approximately 193 m^2 in each trawl. The net efficiency is estimated as 90% based on continued observations of fish escaping above or behind the net.

Fishes were preserved by freezing and they were identified, using taxonomic keys of Whitehead *et al.* (1986) and Bauchot & Pras (1987). The number of all specimens was recorded, and the total length (accuracy 0.01 cm below) and biomass (wet weight, accuracy 0.1g) of fish were determined.

Otoliths and scales were removed from fish and stored dry in labelled envelopes. The scales were removed from the base of the pectoral fin in the longitudinal line. Right otoliths were examined, except in abnormal cases (i.e. broken), where the left was examined, under reflected light with a stereo microscope (OLYMPUS SZ60-PT) having a micrometer eyepiece. The number of opaque zones (winter rings, appearing bright under reflected light) and the

presence of a marginal translucent zone (summer rings, appearing dark under reflected light) were recorded. Otoliths were compared to scale ageing readings made by two investigators and only coincident readings were considered in order to minimise observation errors.

Data Analysis

Measurements of temperature (± 0.1 ºC) and salinity (± 0.1) were recorded at the water surface in each month and were consistent with previous surveys within the area (Rebelo, 1992; Pombo & Rebelo, 2002; Pombo *et al*., 2002a).

Ten fish species were selected for this study consisting of the two most abundant species of each ecological guild, considering the total abundance of two years. Ecological guilds followed the classification of Elliott & Dewailly (1995): (1) ER, estuarine residents; (2) MJ, marine juveniles; (3) MS, marine seasonal; (4) FW, freshwater; (5) MA, marine adventitious; (6) CA, catadromous; and (7) AN, anadromous species.

Species richness, species diversity and evenness indices were calculated using data from the whole community; the temporal and spatial patterns of abundance and biomass were used to indicate the equilibrium stage of the populations (Ludwig & Reynolds, 1988). The species richness (R) was quantified by the Margalef index (Ludwig & Reynolds, 1988): $R = \frac{S-1}{\ln(n)}$, where *S* indicates the total number of species and *n*, the total number of individuals in a sample. Species diversity was quantified using the Shannon-Wiener index (*H'*) (Shannon & Weaver, 1949): $H' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right], i = 1,2,3,\ldots,S$ where *S* indicates the total number of species, n_i the abundance of the *i* species, and *n* the abundance of all species. Evenness (E) was quantified by the index modified by Hill (1973): $E = \frac{\frac{1}{l}-1}{e^{H'}-1} = \frac{N_2-1}{N_1-1}$, where l represents the Simpson index, *H´* the Shannon-Wiener index and N_2 and N_1 represents the diversity number. One-way ANOVA was assessed to test significant differences among species richness and diversity indices between months and between sites within each year and between years. The package

SIGMA-STAT For Windows version 2.03 was used for these analyses (Zar, 1984; Sokal & Rohlf, 1995).

The somatic production of individual fish was computed by the method of Chapman (1978): $P = G.\Delta t.\overline{B}$ where P= production per monthly interval summed both to each year and to cohort; G= instantaneous coefficient of growth; $\overline{B}$ = average monthly population derived from the cohort growth and abundance analysis (Table 3). Negative monthly production values, which may be the result of size-selective mortality and/or migration, have been included in the computations (Chapman, 1978). An example of calculation is given in table 4. The cohorts were determined by the age groups obtained by otoliths and scales readings during each of the two years. In the case of a large group of individuals of similar size, when it was not possible to read all otoliths and scales, fishes were assumed to be of the same age according to the length/age relationship. The total fish production was determined by the sum of the ten dominant fish production and an average of the calculated $P/\overline{B}$ values was used to estimate the production by species of minor importance, i.e. all the other species referred in table 2.

Results

The Structure of Fish Community

In this study, 41,681 specimens comprising 61 teleost species were captured, with a total biomass of 222 kg (Table 1). Of these 61 species, only 33 species were common to both years, 20 species were exclusive to 1999 and 8 were exclusive to 2000 (Table 1). The decrease in number of species, from 1999 to 2000, was due to the absence in the second year of 10 marine adventitious visitors, 8 marine juvenile migrant species and 2 estuarine resident species (Table 2). However, some other species were exclusive of this year: 3 marine adventitious, 2 freshwater, 1 estuarine resident, 1 marine juvenile, and 1 anadromous species. The number of total individuals and also the biomass were similar in both years (Table 1).

Table 1 - Number of individuals, biomass and total number of species in the two years of sampling.

Total	**1999**	**2000**	**Total**
Number of individuals	19,424	22,257	41,681
Biomass (kg)	112.6	109.3	221.9
Samples species number			
Number of species	53	41	61
Exclusive species per year	20	8	
Common species in two years			33

Table 2 - Number of individuals and biomass (g) of fish sampled in 1999 and 2000 grouped by ecological guilds, according to Elliott & Dewailly (1995). Ten selected species are bold represented.

		Abundance		Biomass (g)	
Species	Code name	1999	2000	1999	2000
Estuarine Resident Species					
Ammodytes tobianus	Atob	9	-	102.1	-
Aphia minuta	Amin	48	5	9.3	4.5
Atherina boyeri	**Aboy**	**2,082**	**2,911**	**5,624.7**	**3,074.2**
Gobius ater	Gate	1	4	9.4	54.0
Gobius niger	Gnig	182	235	2,732.5	3,026.8
Gobius paganellus	Gpag	18	2	189.4	13.4
Mugil cephalus	Mcep	8	5	2,457.0	2,056.7
Nerophis ophidion	Noph	1	-	3.0	-
Platichthys flesus	Pfle	121	21	988.5	250.7
Pomatoschistus microps	**Pmic**	**526**	**338**	**443.4**	**192.3**
Pomatoschistus minutus	Pmin	75	47	69.3	105.1
Symphodus melops	Smel	-	1	-	14.8
Syngnathus acus	Sacu	203	200	729.3	1,063.8
Syngnathus typhle	Styp	6	6	15.2	2.6
Marine Juvenile Migrant Species					
Atherina presbyter	**Apre**	**1,011**	**1,225**	**7,078.3**	**6,896.0**
Chelidonichthys lucerna	Cluc	202	32	4,569.9	977.0
Dicentrarchus labrax	**Dlab**	**37**	**757**	**1,456.0**	**7,954.5**
Dicentrarchus punctatus	Dpun	5	-	34.4	-
Diplodus annularis	Dann	2	-	14.9	-
Diplodus sargus	Dsar	20	5	94.3	30.3
Diplodus vulgaris	Dvul	4	-	155.3	-
Pleuronectes platessa	Ppla	1	-	0.1	-
Scophthalmus rhombus	Srho	-	3	-	18.7
Solea senegalensis	Ssen	6	-	96.0	-
Solea solea	Ssol	3	-	41.6	-
Spondyliosoma cantharus	Scan	1	-	89.2	-
Trisopterus luscus	Tlus	4	-	10.4	-
Marine Seasonal Migrant Species					
Chelon labrosus	Clab	140	14	1,846.2	757.4
Ciliata mustela	Cmus	22	6	139.3	212.6
Engraulis encrasicolus	Eenc	352	334	359.6	715.4
Liza aurata	**Laur**	**4,273**	**5,092**	**45,624.5**	**50,237.4**
Sardina pilchardus	**Spil**	**8,739**	**9,478**	**13,683.9**	**13,694.3**

		Abundance		Biomass (g)	
Species	Code name	1999	2000	1999	2000
Freshwater Adventitious Species					
Carassius carassius	Ccar	-	3	-	1,346.4
Gambusia affinis	Gaff	-	4	-	1.9
Marine Adventitious Visitors					
Balistes carolinensis	Bcar	1	-	379.4	-
Boops boops	Bboo	2	1	89.8	0.4
Callionymus lyra	Clyr	12	6	211.1	116.9
Conger conger	Ccon	1	-	0.6	-
Deltentosteus quadrimaculatus	Dqua	1	-	9.0	-
Echiichthys vipera	Evip	-	1	-	19.2
Entelurus aequoraeus	Eaeq	-	1	-	0.8
Hyperoplus lanceolatus	Hlan	1	-	2.6	-
Labrus bergylta	Lber	2	-	140.1	-
Labrus merula	Lmer	1	-	59.4	-
Mullus surmuletus	Msur	21	12	893.3	598.9
Parablennius gattorugine	Pgat	8	10	37.8	45.0
Parablennius sanguinolentus	Psan	1	-	7.6	-
Pomatoschistus marmoratus	Pmar	7	-	22.5	-
Psetta maxima	Pmax	1	-	49.4	-
Scomber scombrus	Ssco	1	-	19.2	-
Solea lascaris	Slas	11	2	55.3	24.1
Sparus aurata	Saur	-	8	-	97.4
Symphodus bailloni	**Sbai**	**93**	**159**	**1,421.3**	**1,417.5**
Symphodus cinereus	Scin	1	1	51.5	4.3
Trachurus trachurus	Ttra	8	5	112.3	56.3
Catadromous Migrant Species					
Anguilla anguilla	**Aang**	**53**	**46**	**2,690.2**	**2,031.8**
Anadromous Migrant Species					
Alosa alosa	Aalo	4	3	287.1	57.5
Alosa fallax	Afal	21	24	551.2	344.1
Gasterosteus aculeatus	Gacu	-	13	-	182.5
Liza ramada	**Lram**	**627**	**1,227**	**10,587.2**	**11,375.7**
Liza saliens	**Lsal**	**444**	**10**	**6,270.6**	**267.1**

The marine seasonal (68%) and estuarine resident species (17%) accounted for 85% of total abundance and 68% of total biomass collected during the whole period (Table 2). Thirteen species were marine juvenile migrant species, comprising 8% of total numbers and 13% of total biomass. Twenty species were transient visitors to the lagoon, but they comprised a low number of the fish collected (1% of total individuals and 3% of total biomass). Only five species were anadromous and one catadromous accounting for 6% of total individuals and 15%

of the total biomass, and there were only two freshwater species which accounted 7 individuals that sporadically occurred in the lagoon (Table 2).

The ten selected species (represented in bold in table 2) comprised 92% of the total abundance in the first year and 95% in the second year, from which six species were present in every sampling site: *S. pilchardus*, *Liza. aurata, Atherina boyeri*, *Atherina presbyter*, *Dicentrarchus labrax*, and *Liza ramada* from which three were evenly distributed in all seasons: *A. boyeri*, *A. presbyter*, and *L. aurata*.

S. pilchardus was the most abundant species in both years comprising 45% of total abundance in the first year, 42% in the second year and 12% of total biomass (Fig. 2). *L. aurata*, also a marine seasonal species, comprised 22% of total numbers in the first year and 23% in the second year and more than 40% of the total biomass (Fig. 2).

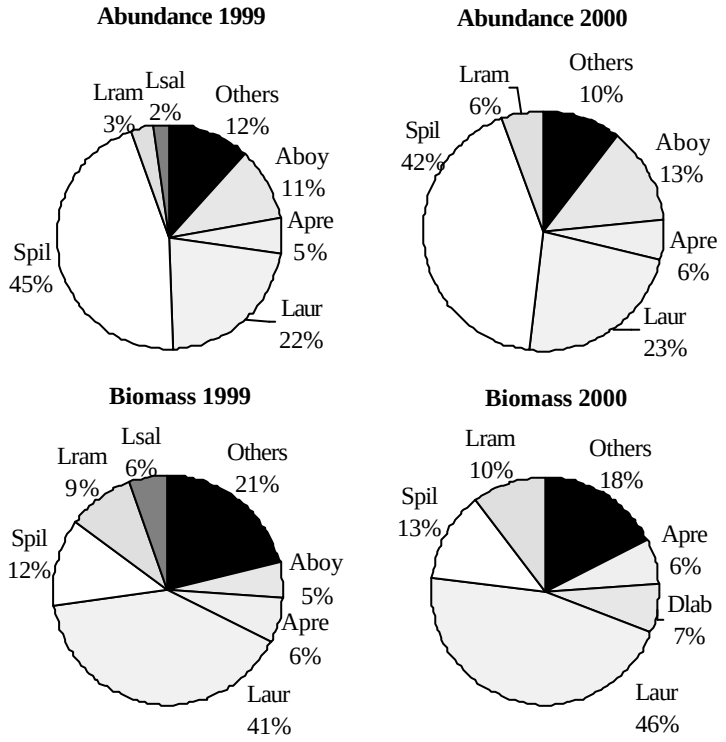

Fig. 2 - Pie charts of percentage of fish abundance and biomass for each year. Species code names are provided in table 2.

The next two most abundant species, *A. boyeri* (resident) and *A. presbyter* (marine juvenile) together accounted for approximately 16% of the total numbers in the first year and 19% in the second year, and about 10% of the total biomass. *D. labrax* occurred in larger numbers in the summer and autumn, while *S. pilchardus*, *L. ramada* and *L. saliens* were more variable seasonally, being absent or rare during winter occurring in greatest numbers in spring, summer, and sometimes autumn.

The average values of temperature and salinity show significant differences seasonally (Fig. 3). Temperature varied from the maximum in summer months (27 ºC) to a minimum species, in winter months (7.6 ºC) and salinity varied from typically freshwater in January and May to marine water (in July and August) (Fig. 3). During periods of maximum freshwater discharge resulting from continued rainy periods, in the second year, the salinity was greatly decreased over the whole lagoon although this was not significant between the two years (p=0.570). The temperature was not statistically significantly different (p=0.801) between the two sampling years.

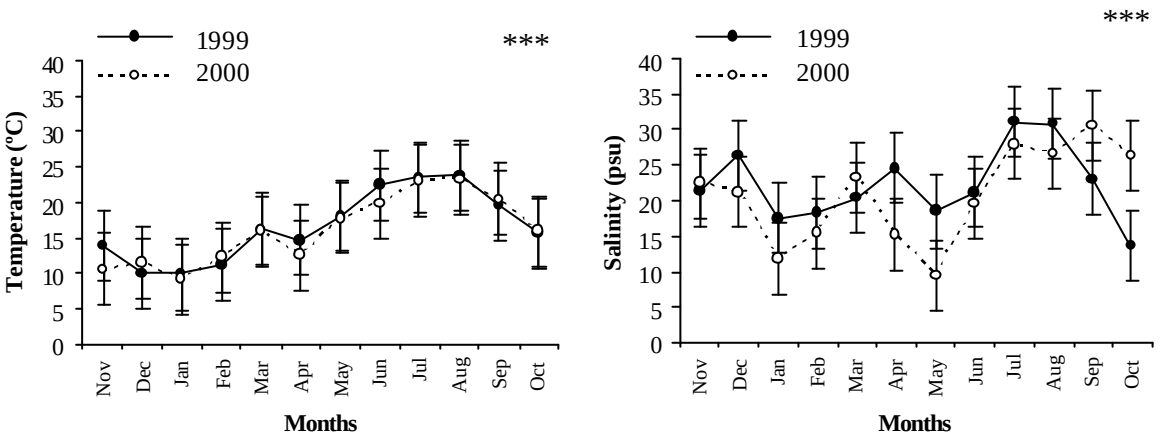

Fig. 3 - Mean temperature and salinity variation ± S.E., per sampling months, in each year. Significantly differences of abiotic parameters between months are shown (***): p≤0.001.

During the two-year period, species richness in the monthly sample was statistically higher in 1999 than in 2000 (p=0.003), but in both years the number of species was consistently higher in spring-summer (from March to September ranging from 15 to 28 species) and lower in autumn-winter (from October to

February ranging from 14 to 23 species) (Fig. 4). The increase in the number of species in spring and summer could be attributed to an influx of marine seasonal migrant species and marine juvenile species in the lagoon. Spatially, species richness showed no consistent trend related to distance from the entrance of the lagoon (Fig. 4) and was higher in 2000 only at three sampling sites (GAF, RIO and VAG) mostly due to the influx of marine adventitious species but also marine seasonal species.

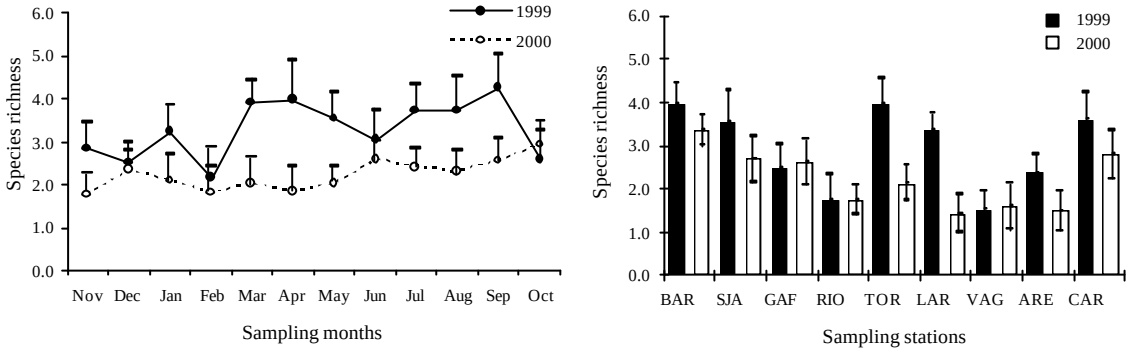

Fig. 4 - Species richness variation ± S.E., per month and sampling sites.

The indices of Shannon-Wiener diversity and evenness each showed a consistent seasonal pattern each year during the study period (Fig. 5). The indices were seasonally significantly different between the years (p=0.008 for Shannon-Wiener, p=0.012 for evenness) being mostly higher in 1999. In terms of abundance, both indices were higher in spring and autumn and lower in May, June and August (Fig 5), which corresponded to the large recruitment of a particular marine seasonal migrant species, *S. pilchardus*. Their capture in June 1999 corresponded to 34% of total abundance in 1999, 24% in May and 31% in August 2000. This resulted in the lowest values of the diversity index and evenness observed during these periods. However, in terms of biomass those differences were relatively small as specimens of *S. pilchardus* that recruit to the lagoon are juveniles with a mean length of 5.2 cm and a mean weight of 1.5 g.

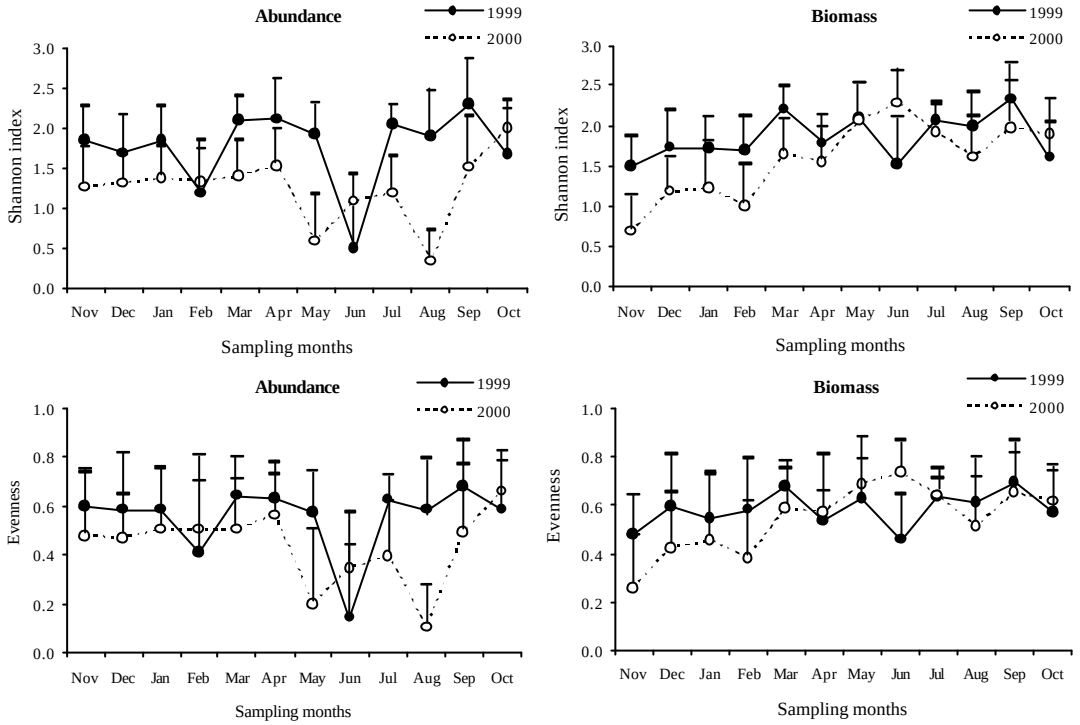

Fig. 5 - Shannon and Evenness indices variation + S.E., per sampling months, by abundance and biomass for each year.

Community Production

The variation of abundance and biomass for each species over the two years of sampling (Table 2) shows that the first year had higher biomass of resident species (including *A. boyeri* and *P. microps*), marine adventitious species (including *S. bailloni*) and diadromous species (including *A. anguilla* and *L. saliens*). In contrast, the second year supported the greatest biomass for few species (*D. labrax*, *L. aurata*, and *L. ramada*) although in most cases the abundance was higher in this year.

The combined production of all fishes in the Ria de Aveiro lagoon was calculated as 90.3 t in the whole lagoon or 2.1 g m^{-2} $year^{-1}$ in the first year and 106.7 t in the whole lagoon or 2.5 g m^{-2} $year^{-1}$ in the second year (Table 3). *S. pilchardus*, particularly the smallest cohort (0^+ age group, 3-10 cm) accounted for the greater proportion of the estuarine lagoon fish production (39% and 34% in the first and second year, respectively). Other important species included *D. labrax* in the second year with production estimates of 0.596 g m^{-2} $year^{-1}$ accounting 24% of total production in the second year. The cohort 0^+ (2-14 cm) accounted with 90%

of production for this species. In terms of ecological guilds, marine seasonal species accounted for about 59% and 46% of the total production, in the first and second year, respectively, largely due to the dominance of *S. pilchardus* in the lagoon. The estuarine resident species accounted for 15% and 10% of total production in the first and second year, respectively. Marine juvenile species accounted for 12% and 31% of total production, for the two years respectively. Diadromous species (anadromous and catadromous together) accounted for 10% and 5% of total production, whereas marine adventitious species accounted for 4% and 5% of total production for each year respectively.

Taking all species together, although the first year was more productive for most of the species, total annual production was greater in 2000, mainly due to the production of juveniles of *D. labrax*, *L. aurata* and also *S. pilchardus*. This annual variability was relatively small compared to the large variation in production values between cohorts, population structure and species.

Table 3 - The production (g m^{-2} $year^{-1}$) of ten selected abundant species and total fish production in the Ria de Aveiro estuarine lagoon.

Ecological guilds	Species	Total Biomass (g)		Annual Production (g m^{-2} $year^{-1}$)	
		1999	2000	1999	2000
Estuarine Residents	*Atherina boyeri*	5,625	3,074	0.127	0.095
	Pomatoschistus microps	443	192	0.033	0.012
Marine Juvenile	*Atherina presbyter*	7,078	6,896	0.126	0.077
	Dicentrarchus labrax	1,456	7,955	0.015	0.596
Marine Seasonal	*Liza aurata*	45,625	50,237	0.251	0.157
	Sardina pilchardus	13,684	13,694	0.824	0.841
Marine Adventitious	*Symphodus bailloni*	1,421	1,418	0.041	0.097
Catadromous	*Anguilla anguilla*	2,690	2,032	0.050	0.024
Anadromous	*Liza ramada*	10,587	11,376	0.061	0.084
	Liza saliens	6,271	267	0.065	0.001
Others		17,735	12,199	0.298	0.250
Total (90% of net efficiency)		**112,615**	**109,340**	1.891	2.234
Total Production				**2.101**	**2.482**

Table 4 - Example of calculation of fish production. Data are from the first year of sampling of the 0+-age group of *A. boyeri*. Production is calculated by the method of Chapman (1978):

$$P = G.\Delta t.\overline{B}$$

Date	Mean weight	Time	Inst. growth rate	Stock numbers	Stock biomass	Mean biomass	Production
	$\overline{W}$	Δt	G	$\hat{N}$	B	$\overline{B}$	P
	g				g	g	g
Nov	1.4			218.0	434.2		
		1.0	0.17			430.5	74.2
Dez	1.7			194.0	426.7		
		1.0	-0.03			252.7	-8.5
Jan	1.6			42.0	78.6		
		1.0	-0.31			54.4	-16.7
Fev	1.2			25.0	30.1		
		2.0	-0.54			15.5	-8.4
Apr	0.4			2.0	0.8		
		1.0	-0.12			11.4	-1.4
May	0.4			70.0	22.0		
		1.0	-0.02			13.4	-0.3
Jun	0.3			21.0	4.8		
		1.0	0.63			12.8	8.0
Jul	0.7			32.0	20.8		
		1.0	0.00			12.4	0.0
Aug	0.7			6.0	3.9		
		1.0	-0.28			6.9	-1.9
Sep	0.5			20.0	9.8		
		1.0	0.61			5.4	3.3
Oct	0.9			1.0	0.9		
		1.0	-1.10			1.7	-1.8
Nov	0.3			8.0	2.4		

Annual production of 0^+-group of *A. boyeri* = SP=46.5 g. $year^{-1}$

Use of Fishery Captures Data

In order to put into perspective the above production data obtained from the scientific survey, this study has attempted to collate data on fishery yields as an indication of the lagoon's productivity. Recent information on fish catches and landings for the Aveiro region have been obtained from the internal reports of Docapesca Portos & Lotas SA.; this includes the fish caught in both the Ria and in the adjacent coastal area (7946 tonnes in 1998; 5837 tonnes in 1999; 5933 tonnes in 2000 and 5834 tonnes in 2001). It is considered that these data are the most accurate available estimates for landings but they have limited value as they are the combined totals for both the Ria and the coastal area. It is estimated that only

5%, i.e. 300-400 tonnes.year^{-1}, of the total catch relates to the lagoon although there are no satisfactory records confirming this proportion. In addition, data have been taken from Reis (1993), from 1956 to 1990 (Fig. 6). These data show that catches were high in the 1950s (about 2000 tonnes.year^{-1}) and then progressively decreasing since then such that in 1998, the fish catch was approximately 400 tonnes.year^{-1}, while from 1999 to 2001, this was approximately 300 tonnes.year^{-1}.

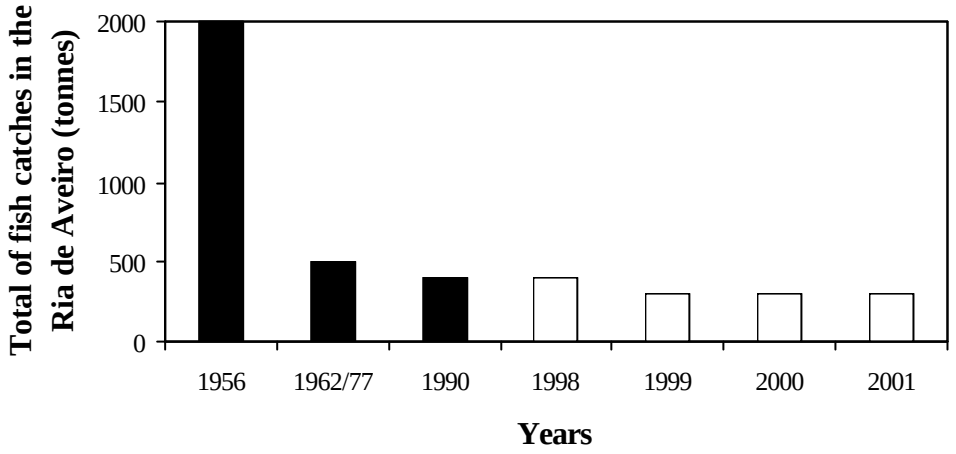

Fig. 6 - Total of fish caught in the Ria de Aveiro. ¦ - data obtained in Reis, (1993); ? - data obtained in internal reports of Docapesca Portos & Lotas SA.

Similarly, there are no accurate records of the catches from individual fishing boats. The present study initially collected information from the commercial fishermen but the data are considered to be too unreliable and variable to be of value.

In addition, where sport and recreational fishing occurs, the records of individual anglers or angling clubs may be of some value. The records of club competitions are often vary detailed (giving the weights and numbers of fish caught, the number of anglers, and the time spent fishing) and may cover many years. However, these competitions are only interested in fish with high commercial values and less valuable fish are not recorded.

Finally, information is available with respect to the number of boats licensed for the Port of Aveiro. In 1998 and 1999 there were 5372 and 6546 boats respectively registered for recreational fishing in the area. Therefore it is suggested that although there are inadequate data regarding the annual and

seasonal frequency of fishing or the amount of fish caught by sport fisherman, this yield may remove a notable part of the total lagoonal fish stocks.

Discussion

The present study and pervious studies have shown that fish production is difficult to estimate accurately in highly variable hydrodynamic environments and for species which have a rapid growth, which migrate according to age and hydrological conditions and whose recruitment is composed of several temporal pulses (Elliott & Hemingway, 2002). Furthermore, fish production is difficult to calculate and by its nature is most accurate for larger and more uniform populations, especially those without large scale migrations into and out of the study area. The main source of inaccuracy is associated with determining population sizes, because of uncertainties in calculating gear efficiency and the relatively low sampling effort or area possible. A main source of error in many production calculations is the accurate delimitation of cohorts (Elliott & Taylor, 1989a) and in the present study, the delimitation of cohorts was associated to fish ageing problems although these errors were reduced by analytical control using two methods of reading and two readers.

The presence of a large population and well-defined population structure, i.e. well-defined cohorts, and a short time interval between sampling, e.g. monthly, will result in good estimates of production (Elliott & Taylor, 1989a, b). Because of this, the present study has only used sample sizes with representative catches of distinct age cohorts to calculate the cohorts' production.

Estimates of total fish removal by natural mortality by piscivorous bird and fish predation, fishing activities or emigration, are also difficult to estimate. Furthermore, without knowledge of the dietary composition the mortality by predators cannot be expressed numerically (Cowley & Whitfield, 2002). It is only through the estimation of abundance and biomass of fish and their prey, that exact computations of production and consumption and thus, calculations of flow of matter and energy at these trophic levels can be made (Thiel, 2001). It is of note that this information is available for only a few areas (Elliott & Hemingway, 2002).

Marine migrant species transfer large amounts of energy, accumulated in estuaries and lagoons, to coastal marine ecosystems (Cowley & Whitfield, 2002) and, notably, fish exports from these systems are of high value and provide a direct link to higher trophic levels (Nixon *et al*., 1986). Hence, reductions in the total number of emigrating estuarine fishes, due to natural or human effects in the environment, could highly influence the biodiversity and stability of neighbouring inshore coastal ecosystems (Cowley & Whitfield, 2002). In addition, these emigrating fishes are also known to contribute significant amounts of biomass for coastal recreational and commercial fisheries (Houde & Rutherford, 1993).

Within the natural environmental factors, temperature was found to be the most important abiotic factor affecting the abundance distribution of fish assemblage in the Ria de Aveiro (Pombo *et al*., 2003), proving to be the best predictor of total abundance, which was more related to the seasonal migrations than to spatial migrations. Similar results were observed in other regions of the world (Jones *et al*., 1996; Marshall & Elliott, 1998; Kuo *et al*., 2001). While temperature will affect growth and thus production by the fish, it is not possible to separate its primary influences, such as on growth and respiration, from secondary influences, such as on the success of previous spawning and recruitment events, which will eventually influence the total productivity of the area.

The present study has shown that the presence, abundance and biomass of the seasonal migrant species *S. pilchardus* were a major driver of the dynamics and structure of fish assemblages in the lagoon. This species was the most consistent species and contributed largely to the low values in the diversity parameters, particularly in May, June and August, when water temperature was higher and when this species recruits to the lagoon with a high abundance juveniles (<1+ cohort) (Rebelo, 1992; Rebelo & Pombo, 2001). Thus, *S. pilchardus* was the most abundant species and accounted for most of the fish biomass (about 12% in each year) and production (39 and 34% in the first and second year, respectively). The success of this species is attributed to the stage 0^+-age group, which colonises the lagoon abundantly in a particular period, because the production of small fish in the fast-growing period of their lives (the youngest age-group) is usually greater than of all other age-groups combined (Chapman, 1978).

This agrees with and reinforces other studies which indicate the predominance of juvenile and fast growing individuals and species with small individuals in estuaries, hence giving these areas a high production and productivity (Elliott & Hemingway, 2002).

The total number of marine seasonal species was low but their abundance and biomass was very high. This is in contrast to the marine adventitious species which in the Ria as elsewhere (Elliott & Taylor, 1989b), have a high number of species but a low abundance and biomass; *S. bailloni* only contributed to 2.2% and 4.3% of total production, in each year respectively. Diadromous (catadromous or anadromous) migrant species, which use the lagoon to pass between salt and freshwater for spawning and feeding, included *A. Anguilla* (a traditional and economically important species for the region), *L. ramada* and *L. saliens* (some of the largest collected specimens). Few data exist on the biological production of *A. anguilla* in other studies, partly because the difficulty of obtaining accurate information because of intensive poaching in certain areas and an incomplete control of landings, lead to an underestimating of the fisheries production (Elliott & Hemingway, 2002). In this lagoon, this species represented low production (0.05 and 0.02 g m^{-2} $year^{-1}$, in each year of sampling) comparing to 0.08 and 2.4 g m^{-2} $year^{-1}$ in the North Sea (Oosterschelde estuary, and Elbe estuary, respectively) (Hostens & Hamerlynck, 1994; Thiel *et al*., 1997 *in* Elliott & Hemingway, 2002). On the other hand, estuarine resident species, which spend their entire life cycle in the estuary but therefore have a minimal role in directly exporting energy to the adjacent marine environment (Bennett & Branch, 1990), such as *A. boyeri* and *P. microps*, are generally small but can achieve considerable densities and biomass within estuaries. In the first year, those two species contributed to 8.4% of total production. This is similar to other transitional water bodies in which the estuarine residents and the marine juvenile species contribute the largest part to the total community production (e.g. Elliott & Taylor, 1989b).

The low salinity conditions, especially between April and June, are a dominant feature influencing the recruitment to the lagoon of marine seasonal migrant species and the marine adventitious visitors that colonise the lagoon as well as those species entering the lagoon during this period to spawn (Pombo &

Rebelo, 2002; Pombo *et al*., 2003). The response of many species to salinity may vary with life stage and the freshwater discharge during the continued rainy periods in the second year of sampling could have determined the migration to the lagoon because of the production of a barrier to penetration by stenohaline marine species; therefore the number of species was remarkably lower in the second year of sampling, even though the abundance of some species was particularly very high. Similar patterns were observed in the Bothnian Sea (Thorman, 1986) and the Humber Estuary (Marshall & Elliott, 1998) with positive correlations between minimum salinity and average species number. On the other hand, biomass of dominant species was higher in summer, near the mouth of the lagoon, in the middle of the main channel and the inner channel, where high salinity levels occurred, consequently affecting the total productivity.

Although for most species, the first year showed higher production, the increase of total population production during the two consequent years could suggest an improvement of total fish stocks. This appeared to be the result of a high abundance of marine migrant species, possibly due to climatic conditions, for example, during the sampling period analysed here, depth significantly decreased, while pH significantly increased, from the first to the second year (Pombo *et al*., 2003). Strong rainfalls in 2000, and consequently the raised flows of water leaded to a bedstead deepen, transporting sediments from one region to another, changing substantially the lagoon sediments and consequently modifying the distribution of fish fauna (Perez-Ruzafa *et al*., 1991).

Other marine species with a high production as the result of a high occurrence of juveniles were *D. labrax*, especially in the second year, and *L. aurata*. In Greece, the natural production of *D. labrax* in the Messolonghi-Etolikon lagoon based on data from the traps and fish barriers, was approximately 0.04 g m^{-2} $year^{-1}$ (Elliott & Hemingway, 2002), and in this lagoon in the second year, the production was esteemed of 0.60 g m^{-2} $year^{-1}$. In the Forth Estuary (Scotland), Elliott & Taylor (1989b) obtained values ranging from 0.001 to 1.455 g m^{-2} $year^{-1}$ for seven marine dependent species.

The production values of the whole lagoon also enable the functioning of the Ria de Aveiro to be compared with other areas with a temperate climate (Table 5)

(Cowley & Whitfield, 2002; Elliott & Hemingway, 2002). Over the study period there was a production of 2.1 g m^{-2} $year^{-1}$ in the first year and 2.5 g m^{-2} $year^{-1}$ in the second year.

Table 5 - Fish community production estimates in temperate estuaries. Adapted from Cowley & Whitfield (2002) and Elliott & Hemingway (2002).* - based on information from fisheries yield; ** - based on summation of production estimates of selected component species.

Location	Fish Production (g m^{-2} $year^{-1}$)	References
Flax Pond, New York	108 - 146**	Hall & Woodwell (unpubl. data)
Wadden Sea, Netherlands	10.0*	Postma & Rauck (1979)
North Sea	2.5	Steele, 1974
Forth Estuary, North Sea	4.3**	Elliott & Taylor (1989)
Southern North Sea	5.2*	Korringa (1967)
Skagerrak & Kattegat (Sweden)	2.5 - 3.3	Pihl & Rosenberg (1982)
North Baltic Sea	1.25	Ankar, 1977
Italy	9.0 - 17.0*	DeAngelis (1960)
Lagoon systems of the Bay of Cadiz, Spain	4 - 47*	Drake *et al.* (1984)
Ria de Aveiro estuarine lagoon, west coast of Portugal	2.1 - 2.5**	Present study

According to Cowley & Whitfield (2002) the estuarine fish community productivity increases with decreasing latitude (i.e. towards the tropics), however, this is not always true. Table 5 indicates that the production values, which ranged from 1.3 to 47 g m^{-2} $year^{-1}$, are representative of total fish community productivity in estuarine environments. It is of note that the fish production in the Ria de Aveiro appears to be lower than most other similar estuarine ecosystems, as it is an area high river influences, low depth, and very particular characteristics that makes it a peculiar semi-closed system, and therefore distinct from the other estuaries. In addition, it is difficult to further compare these different areas because of the differing methods and spatio-temporal scales used (Elliott & Hemingway, 2002).

The different population production estimates between the two subsequent years are relatively close despite the differences in community and populations structure. The calculations for single cohorts are inherently difficult given that organisms may repeatedly migrate into and out of the estuary at different ages and thus be counted as positive production on some occasions and negative production in others. Although the estimates achieved here are the first for the lagoon, there is a need to further quantify the uses of that production in the lagoon,

such as for fisheries or by higher predators, to assess what production is exported to marine areas, and to determine the relative proportions of production by migrating marine species that have different production both in estuarine habitats and coastal areas.

The present study has considered the fishing effort, as commercial landings from the fishing port, which although it should be treated with caution, has indicated that the annual fish catches was about 300 tonnes in each year (from 1998 to 2000), which corresponded to three times higher than the estimated production for the lagoon, i.e. Man is operating as a predator removing a high proportion to other top predators.

Furthermore, although the removal of fish by leisure fishing has not been quantified, there is circumstantial evidence to suggest that it will be significant amount for some species in the lagoon, mainly *Solea solea*, *Platichthys flesus*, *A. anguilla* and *D. labrax*, as indicated during personal communications with fisherman.

The amount caught by professional fishing and by sport fishing could not be accurately estimated although this together with the previous commercial stocks may indicate an overexploitation of lagoonal fish community. Hence although there is a long tradition of artisinal fisheries in the lagoon area, the coastal industrial fishery is a relatively recent development. Therefore it is necessary to recommend, especially given the uncertainty in the present estimates of production against a background of the precautionary principle, that there should be a careful management and efficient policing of the harbour, which are essential prerequisites to ensure a healthy aquatic environment and sustainable catches in the future (Whitfield, 1996).

Conclusion

The present study has provided the first attempt at calculating fish production in the Ria de Aveiro estuarine coastal lagoon and highlights some difficulties associated with obtaining reliable estimates. The study also draws attention to the dynamic and complex nature of estuarine fish production due to fluctuating levels of population biomass arising from recruitment variability, mortality and fisheries.

The high production level of *S. pilchardus* indicates that this seasonal migrant species plays an important role in energy flow within the lagoon and possibly a dominant role in exporting the estuarine production (energy) to the nearshore coastal environment. The study emphasises the need for continuing long-term studies to assess further both the relationship between estuarine and marine survey data and the fish stock and catch assessment data as well as determining the potential value of estuary data in the management of marine fish stocks.

A significant increase in the use of the lagoon by the public in general, combined with the reduction in access to alternative fisheries for many estuarine commercial and recreational fishermen, has resulted in a need to review the current management practices for the commercial fishery and its effects on fish stocks.

It is also concluded that fish data have a role in water quality and estuarine management (Whitfield, 1996; Whitfield & Elliott, 2002) but further studies are required to evaluate the state of risk in the near future of the system in relation to the overexploitation of its resources, for achieving an integrated management of the ecosystem, as well as for anticipating the capacity of the area to absorb future demands.

Acknowledgements

The authors would like to thank the University of Aveiro, the Foundation for Science and Technology and the European Social Fund for their financial support for this study. The authors are also very grateful to all the students who helped in the field and laboratory work.

References

Aneer, G.; Blomquist, E.M.; Hallbäck, H.; Mattila, J.; Nellbring, S.; Skóra, K. & Urho, L. 1992. Methods for sampling and observation of shallow water fish. *The Baltic Marine Biologists,* 13: 1-20.

Arruda, L.M.; Andrade, J.P. & Cunha, M.M. 1988. Abundance, diversity and community structure of the fish population in the Ria de Aveiro (Portugal). *Oceanol. Acta.*, 11 (3): 235-240.

Barrosa, J.O. 1980. A Ria de Aveiro e a sua influência na economia da região. *Rec. Hídric.*, 1 (3): 83-96.

Bauchot, M.L. & Pras, A. 1987. *Guía de los peces de mar de España y de Europa.* Ediciones Omega, Barcelona.

Bennett, B.A. & Branch, G.M. 1990. Relationships between production and consumption of prey species in the Bot, a cool temperate South African estuary. *Estuar. Coast. Shelf Sci.*, 31: 139-155.

Borrego, C.; Cruz, M.M. & Gonçalves, P. 1994. *Estudo de avaliação da vulnerabilidade da capacidade de recepção das águas costeiras em Portugal. Relatório R 3.2. Meios receptores e suas características: (Be 1) - Ria de Aveiro, Pateira de Fermentelos e Barrinha de Mira.* IDAD. Instituto de Hidráulica e Recursos Hídricos, Universidade de Aveiro, Aveiro.

Chapman, D.W. 1978. Production - Chapter 8, In: Bagenal, T. (Ed.), *Methods for the Assessment of Fish Production in Fresh Waters*. 3rd Ed. Blackwell, Oxford. 202-217 p.

Cowley, P.D. & Whitfield, A.K. 2002. Biomass and production estimates of a fish community in a small South African estuary 61. *J. Fish Biol.*, (Supplement A): 74-89.

Cunha, M.M.P.R. 1999. Peracaridan crustacea in Ria de Aveiro (NW Portugal): taxonomic composition and spatio-temporal structure of the assemblages; life history and secondary production of Corophium multisetosum Stock, 1952 (Amphipoda, Corophiidae). Ph. D. Thesis, Univ. Aveiro, Portugal.

Elliott, M. & Dewailly, F. 1995. The structure and components of European estuarine fish assemblages. *Neth. J. Aquac. Ecol.*, 29 (3-4): 397-417.

Elliott, M. & Hemingway, K.L. (Eds.). 2002. *Fishes in Estuaries*. Blackwell Science, Oxford.

Elliott, M. & Taylor, C.J.L. 1989 a. The production ecology of the subtidal benthos of the Forth Estuary, Scotland. *Sci. Mar.*, 53(2-3): 531-541.

Elliott, M. & Taylor, C.J.L. 1989 b. The structure and functioning of an estuarine/marine fish community in the Forth Estuary, Scotland. Proceedings of the 21st. European Marine Biology Symposium, Gdansk, September, 1986. Polish Academy of Sciences - Institute of Oceanology, 227-240.

Hill, M.O. 1973. Diversity and evenness: A unifying notation and its consequences. *Ecologie*, 54: 427-432.

Hostens, K. & Hamerlynck, O. 1994. The mobile epifauna of soft bottoms in the subtidal Oosterschelde estuary: structure, function and impact of the storm-surge barrier. *Hydrobiol.*, 282/283: 479-496.

Houde, E.D. & Rutherford, E.S. 1993. Recent trends in estuaries fisheries: predictions of fish production and yield. *Estuaries*, 16: 161-176.

JAPA. 1993. *Estudo de impacto ambiental – desassoreamento da Ria de Aveiro, 1ª fase*. Junta Autónoma do Porto de Aveiro. Edição do Porto de Aveiro, Aveiro.

Jones, G.K.; Baker, J.L.; Edyvane, K. & Wright G.J. 1996. Nearshore fish community of the Port River-Baker Inlet Estuary, South Australia. I. Effect of the thermal effluent on the fish community structure, and distribution and growth of economically important fish species. *Mar. Freshwater Res.,* 47: 785-99.

Kuo, S.-R.; Lin, H.-J. & Shao, K.-T. 2001. Seasonal changes in abundance and composition of the fish assemblage in Chiku lagoon, Southwestern Taiwan. *Bull. Mar. Sci*., 68 (1): 85-99.

Ludwig, J.A. & Reynolds, J.F. 1988. *Statistical Ecology. A primer on methods and computing.* Wiley-Interscience Publications, New York.

Mahon, R.; Balon, E.K. & Noakes, D.L.G. 1979. Distribution, community structure and production of fishes in the upper Speed River, Ontario: a preimpoundment study. *Environ. Biol. Fish.,* 4: 219-244.

Marshall, S. & Elliott M. 1998. Environmental influences on the fish assemblage of the Humber Estuary, U.K. *Estuar., Coast. Shelf Sci*., 46: 175-184.

McLusky, D.S. & Elliott, M. 2004. The Estuarine Ecosystem: ecology, threats and management. (3rd Edition.). Oxford University Press, Oxford.

Morgado, F.M.R. 1997. Ecologia da zooplâncton da Ria de Aveiro - caracterização espácio-temporal, transporte longitudinal e dinâmica tidal, nictemeral e lunar. Ph.D. Thesis, Univ. Aveiro, Portugal.

Morgan, N.C. 1980. Secondary production. In: Le Cren, E.D. & LoweMcConnel, R.H. (Eds), *The functioning of freshwater ecosystems*. University Press. Cambridge. 247-340 p.

Nixon, S.W.; Oviatt, C.A.; Frithsen, J. & Sullivan, B. 1986. Nutrients and the productivity of estuarine and coastal marine ecosystems. *Journal of the Limnological Society of southern Africa,* 12: 43-71.

Nobre, A.; Afreixo, J. & Macedo, J. 1915. *A Ria de Aveiro, Relatório oficial do regulamento da Ria de 28 de Dezembro de 1912.* Imprensa Nacional, Lisboa.

Osório, B. 1912. Pescas e peixes. Uma nota relativa à pesca e aos peixes da Ria de Aveiro. *Bol. Soc. Geogr. Lisboa,* 30(4-5): 216-224.

Perez- Ruzafa, A.; Marcos-Diego, C. & Rós, J.D. 1991. Environmental and biological changes related to recent human activities in the Mar Menor (SE of Spain). *Mar. Pollut. Bull*., 23: 747-751.

Pombo, L. & Rebelo, J.E. 2002. Spatial and temporal organisation of a coastal lagoon fish community – Ria de Aveiro, Portugal. *Cybium*, 26 (3): 185-196.

Pombo, L.; Elliott, M. & Rebelo, J.E. 2002 a. Changes in the fish fauna of the Ria de Aveiro estuarine lagoon (Portugal) during the twentieth century. *J. Fish Biol*., 61 (Supplement A): 167-181.

Pombo, L.; Dias, C. & Rebelo, J.E. 2002 b. Diet comparison between *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal. *Rev. Biologia (Lisboa)*, 20: 59-72.

Pombo, L.; Lopes, C. & Rebelo, J.E. 2002 c. A comparison study on the age and growth of *Atherina boyeri* Risso, 1810 and *Atherina presbyter* Cuvier, 1829 in the Ria de Aveiro, Portugal. *Rev. Biologia (Lisboa)*, 20: 47-58.

Pombo, L.; Dias, C.; Lopes, C. & Rebelo, J.E. 2003. Fishes, Cuttlefishes and the environmental status of Ria de Aveiro estuarine lagoon (Portugal). *Rev. Biologia (Lisboa)*, 21: 103-118.

Rebelo, J.E. & Pombo, L. 2001. *Os peixes da Ria de Aveiro – diversidade, ecologia e distribuição.* Câmara Municipal de Aveiro, Aveiro.

Rebelo, J.E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries*., 15 (3): 403-415.

Reis, A. 1993. *Memórias da Natureza*. Câmara Municipal de Aveiro, Aveiro.

Shannon, C.E. & Weaver, W. 1949. *The mathematical theory of communication*. University of Illinois Press, Urbana, IL.

Sokal, R.R. & Rohlf, F.J. 1995. *Biometry*. 3rd ed. W.H. Freeman and company, New York.

Thiel, R. 2001. Spatial gradients of food consumption and production of juvenile fish in the lower River Elbe. *Arch. Hydrobiol. Suppl*., 135/2-4: 441-462.

Thiel, R.; Nellen, W.; Sepulveda, A.; Oesmann, S.; Tebbe, K. & Drenkelfort, C. 1997. Spatial gradients of food consumption and production of dominant fish species in the Elbe estuary, Germany. ICES Annual Conference, Baltimore.

Thorman, S. 1986. Seasonal colonisation and effects of salinity and temperature on species richness and abundance of fish of some brackish and estuarine shallow waters in Sweden. *Holarctic Ecology*. 9, 126-132.

Whitehead, P.J.P.; Bauchot, M.-L.; Hureau, J.-C.; Nielsen, J. & Tortonese, E. 1986. *Fishes of the North-eastern Atlantic and the Mediterranean*. 3 vols. UNESCO, U.K.

Whitfield, A.K. & Elliott, M. 2002. Fishes as indicators of environmental and ecological changes within estuaries – a review of progress and some suggestions for the future. *J. Fish Biol*., 61 (Suppl. A): 229-250.

Whitfield, A.K. 1996. Fishes and the environmental status of South African estuaries. *Fish. Manage. Ecol.*, 3: 45-57.

Wooton, R.J. 1986. Problems in the estimation of food consumption and fecundity in fish production studies. *Poland Archive of Hydrobiology*, 33: 263-276.

Zar, J.H. 1984. *Biostatistical Analysis*. 2nd ed. Prentice-Hall, Inc., New Jersey.

Discussion

It is of utmost importance for ecologists to determine, or at least, estimate the carrying capacity of fish and thus the repercussions of whether the ecosystem tends to equilibrium in terms of gains and/or losses of energy within the systems.

Carrying capacity can be regarded as the amount of a population of one species or community of several species which can be supported by an area and where that support related to one of the major resources – space, food and reproductive partners (Elliott & Hemingway, 2002). In this, it is necessary to determine how the carrying capacity of an ecosystem is regulated – by physical and resulting food-web processes ("bottom-up"), or by the effects of variable fish abundance and predation on their prey ('top-down processes'). If it is from the bottom-up, then one would expect direct linkages with climate variability. If it is regulated by fish abundance (in effect "top-down" control, or perhaps better described as "self-regulating" control), linkages with climate variability may be less direct and anthropogenic effects, e.g. fishing, changes to habitat and rearing conditions, etc., may be more important (Perry *et al*., 1998).

Distinguishing bottom-up or self-regulating control of fish production in a lagoon is not simple. It is difficult to determine what fraction of fish production is affected by migrant species that move between the lagoon and the sea and that in turn will cause a net loss or export of secondary production. Another difficulty is identifying when control on fish production has been exerted by food web processes, or by the fish themselves. For example, if fish production were limited by bottom-up processes, the responses in fish should be independent of fish density, although these responses may be more severe when fish density is higher. If fish production were limited by fish density (e.g. by reducing prey abundance), then the effect should be most apparent at very high fish densities (Perry *et al*., 1998).

It is hypothesised that fish production of the lagoon is likely to be controlled by self-regulated by the effects of fish abundance rather than bottom-up processes, because fishing, other anthropogenic effects, and environment conditions appear to have a major role in the control of fishing stocks than food web processes.

The different values of production in the two subsequent years for each species are directly related to the fact that organisms could repeatedly migrate into and out of the estuary at different ages and thus be counted as positive production on some occasions and negative production in others, in individual cohort calculations. There is also need to further quantify the loss of production in the lagoon and assess what production is exported to marine areas, and to determine the relative proportions of production by migrating marine species that have different production both in estuarine habitats and coastal areas. It is also of importance to determine what fish production is exported via bird and epibenthic megafaunal predation. This constitutes a lack of information that is needed to be provided by future research. The present study has highlighted that sardine was the most important fish species in terms of the consumption and production processes of the whole fish community in the lagoon, and that it might play a dominant role in terms of exporting estuarine production to the nearshore coastal environment.

An important finding is that there is no single “best” measure of the impact of habitat alteration on a fish population (Hays *et al*., 1996). The density-dependent responses of a species depend upon its biology and the way that habitat alteration affects its vital processes such as growth rates. Further, habitat alterations do not necessarily alter all population characteristics to the same extend. For example, relatively small changes in recruitment can substantially change carrying capacity, while producing a small change in the surplus production of the population (Hays *et al.*, 1996). Pragmatically, this means that the impact of a habitat altering action needs to be evaluated across several population level descriptors.

For abundant populations, surplus production is perhaps most important because it determines the level of harvest that a population can sustain. For species at a low level of abundance or threatened and endangered species, the change in recruitment and surplus production at low stock levels would be the most appropriate responses to compare (Hays *et al*., 1996). Thus, the approach proposed here is useful in linking the characteristics of the environment to the population dynamics of a species at all levels of abundance.

The human-induced direct and indirect degradation of common fisheries resources might cause impacts at the ecosystem level, jeopardising the fundamental and demand-derived ecosystem services generated by fish with consequences for biodiversity, and ecosystem resilience (Naeem *et al*., 1994; Perrings *et al*., 1995).

Gradual loss of resilience due to human activities may be dramatically manifested as a rapid change to an alternate stable state (Holmlund & Hammer, 1999). Thus, pollution, overfishing, intense activities of the industrial sector, the fishing port, dredging, among many others, represent an important ecological impact in the lagoon.

Fishing activities, for example, were found to be three times higher than the fish production estimates in a year. Thus, the lagoon needs to be managed carefully to reduce the impacts in order to preserve its resources in the future.

The internal reports of Docapesca Portos & Lotas SA indicate the evolution of fishing during recent years. In global terms the fishing decreased greatly from the 1950's to the 1960's and 1970's and then remained similar during the last years. There is a lack of data about the production estimates along those years, but they appear to decrease with fishing. In the most recent years, fishing appeared to be constant, in line with the fish somatic production (at least during the two years of this study). This could be an indication that the system is in equilibrium if there was not such a discrepancy between the relationship between fishing and fish production; these features are of concern and warrant further study.

Despite the knowledge that most statistics underestimate the amount of fish landed (Homer *et al*., 1981) and that the fish production estimates was not absolutely accurate (because of the methodological difficulties and inherent errors presented previously), at least the approach gives an indication of the state of the risk of the system.

The main advantage of using commercial fishery statistics is the good coverage they often provide of both area and time. However, even if reasonable accurate estimates of landings are available, there still exist two main problems affecting the use of such data. First, fishing activities select for the most valuable species and areas where these are concentrated; this is an addition to the inherent

selectivity of the gear used. Secondly, unless effort can be assumed to be constant through time or from area to area, the catch/landing data must be expressed in relation to the effort applied. Effort can be expressed most simply in terms of numbers of boats or hours fished (i.e. CPUE, catch per unit effort), but the estimation of standard effort in a mixed and/or developing fisheries is notoriously difficult.

The capacity of fishing in relation to the available resources constitutes serious problems in the fish sector. One of the priorities will be finding an ecologically sustainable balance and economically advantageous, that allows fishing and fish companies to re-establish the competitiveness without putting at risk the natural resources. This balance includes, among others aspects, respecting the minimum sizes of capture considered by law for each species and the use of selective techniques of fishing that might be an indispensable way to a sustainable and responsible exploration of the resources. For example, the management of an ecosystem will often result in an initial decrease of capture, allowing the size development of species that were intensively captured before (Hansson, 1999).

Such ecosystem-based management approaches, must rely on both scientific and traditional ecological knowledge. Less emphasis should put on controlling how much fish that can be harvested. Instead, regulations must focus on when, where and how to fish, taking into account the spatial and temporal life-supporting systems of fish (Acheson *et al*., 1998).

In summary, management needs to be directed towards a multi-hierarchial, ecosystem-based approach which links the actions of populations to ecosystems properties, including functional diversity and resilience (Schultze & Mooney, 1994; Lawton & Jones, 1995; Carpenter & Turner, 1998).

Finally, comparing the fish production estimates (2.1 and 2.5 g $m^{-2}year^{-1}$ in each year, respectively) with elsewhere it is possible to note that it was lower than most ecosystems but it was at the same level of some other ecosystems. The production values of the other systems analysed ranged from 1.3 to 47 g $m^{-2}year^{-1}$ (Cowley & Whitfield, 2002; Elliott & Hemingway, 2002), although the comparability

is difficult as different methods were used for estimating productivity (Elliott & Hemingway, 2002).

In conclusion, this study has provided the first attempt at calculating fish production in an estuarine coastal lagoon and highlights some difficulties associated with obtaining reliable estimates. The study also draws attention to the dynamic and complex nature of estuarine fish production due to fluctuating levels of population production arising from recruitment variability and mortality. One of the main concerns about mortality is respect to the fishing activities that seamed to be much higher than the production that the lagoon supports. The high production value obtained for *Sardina pilchardus* indicates that this seasonal migrant species plays an important role in energy flow within the lagoon and possibly a dominant role in terms of exporting estuarine production (energy) to the nearshore coastal environment.

References

Acheson, J.M.; Wilson, J.A. & Stenbeck, R.S. 1998. Managing chaotic fisheries. In: Berkes, F.; Folke, C. & Colding, J. (Eds.). *Linking social and ecological systems*. Cambridge University Press. Cambridge. 390-413 p.

Anon. 1998. *Biosfera, Comunicação e Imagem, Lda. Áreas Protegidas do Litoral Português*. Instituto da Conservação da Natureza (ICN), Lisboa.

Borrego, C.; Luís, A. & Margalha, J. 1994. *Estudo da avaliação da vulnerabilidade da capacidade de recepção das águas e zonas costeiras em Portugal – Bases para um estatuto de protecção da Ria de Aveiro*: *9-55.* IDAD - Instituto de Ambiente e Desenvolvimento, Aveiro.

Blaber, S.J.M.; Cyrus, D.P.; Albaret, J.J.; Ching, C.V.; Day, J.W.; Elliott, M.; Fonseca, M.S.; Hoss, D.E.; Orensanz, J.; Potter, I.C. & Silvert, W. 2000. Effects of fishing on the structure and functioning of estuarine and nearshore ecosystems. *ICES Journal of Marine Science,* 57(3): 590-602.

Carpenter, S.R. & Turner, M. 1998. At last: a journal devoted to ecosystem science. *Ecosystems*, 1: 1-5.

Costanza, R.; D'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J.; Raskin, R.G.; Sutton, P. & van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387: 253-260.

Correll, D.L. 1978. Estuarine productivity. *Bioscience*, 28: 646-650.

Cowley, P.D. & Whitfield, A.K., 2002. Biomass and production estimates of a fish community in a small South African estuary 61. *J. Fish Biol.* (Supplement A): 74-89.

Elliott, M. & Hemingway, K.L. (Eds.). 2002. *Fishes in Estuaries*. Blackwell Science, Oxford.

Gonçalves, P. & Sobreiro, A. 1992. *Um contributo para a redinamização do Salgado de Aveiro*. Universidade de Coimbra, Coimbra.

Grange, N.; Whitfield, A.K.; De Villiers, C.J. & Allanson, B.R. 2000. The responses of two estuaries on the Eastern Cape Coast of South Africa to varying freshwater inflow: implications for environmental management of freshwater resources. *Aquat. Conserv.: Mar. Freshwat. Ecosyst.*, 10: 155-177.

Hansson, S. 1999. Ecological aspects on fisheries management. Ecosystem management – Can we make it operational? *International Council for the Exploration of the Sea*, 4: 1-5.

Hayes, D.B.; Ferreri, C.P. & Taylor, W.W. 1996. Linking fish habitat to their population dynamics. *Can. J. Fish. Aquat. Sci*., 53 (Suppl. 1): 383-390.

Holmlund, C.M. & Hammer, M. 1999. Ecosystem services generated by fish populations. *Ecol. Econ.*, 29: 253-268.

Homer, M.; Mihursky, J.A. & Jones, P. 1981. Quantitative approaches towards characterizing estuarine fish populations and communities. In: Schaefer, R.H. (Ed.), Proceedings of the 4th Ann.Mtg.Amer. Soc, Potomac chapter. 1-43 p.

Jones, G.K., Baker, J.L, Edyvane, K. & Wright G.J. 1996. Nearshore fish community of the Port River-Baker Inlet Estuary, South Australia. I. Effect of the thermal effluent on the fish community structure, and distribution and growth of economically important fish species. *Mar. Freshwater Res*., 47: 785-99.

Lawton, J.H. & Jones, C.G. 1995. Linking species and ecosystems: organisms as ecosystems engineers. In: Jones, C.G. & Lawton, J.H. (Eds.), *Linking Species and Ecosystems*. Chapman and Hall. London. 141-150 p.

McLusky, D. & Elliott, M. 2004. *The Estuarine Ecosystem: ecology, threats and management*, 3rd Ed. OUP, Oxford.

Minns, C.K.; Kelso, J.R.M. & Randall, R.G. 1996. Detecting the response of fish to habitat alterations in freshwater ecosystems. *Can. J. Fish. Aquat. Sci.*, 53 (Suppl. 1): 403-414.

Naeem, S.; Thompson, L.J.; Lawler, S.P.; Lawton, J.H. & Woodfin, R.M. 1994. Declining biodiversity can alter the performance of ecosystems. *Nature*, 369: 734-737.

Odum, W.E. 1971. *Fundamentals of Ecology*. W. B. Saunders, Philadelphia.

Perrings, C.A.; Mäler, K.-G.; Folke, C.; Holling, C.S. & Jansson, B.-O. 1995. Biodiversity conservation and economic development: the policy problem. In: Perrings, C.A.; Mäler, K.-G.; Folke, C.; Holling, C.S. & Jansson, B.-O. (Eds.), *Biodiversity Conservation*. Kluwer. Dordrecht. 3-21 p.

Perry, R.I.; Welch, D.W.; Harrison, P.J.; Mackas, D.L. & Denman, K.L. 1998. Epipelagic fish production in the open Subarctic Pacific: bottom up pr self-regulating control? *Can. J. Fish. Aquat. Sci*., 55: 26-32.

Randall, R.G.; Kelso, J.R.M. & Minns, C.K. 1995. Fish production in freshwaters: are rivers more productive than lakes? *Can. J. Fish. Aquat. Sci.*, 52: 631-643.

Rebelo, J.E. & Pombo, L. 2001. *Os Peixes da Ria de Aveiro*. Câmara Municipal de Aveiro, Aveiro.

Reis, A. 1993. *Memórias da Natureza*. Câmara Municipal de Aveiro, Aveiro.

Ricker, W.E. 1971. *Methods for assessment of fish production in Fresh Waters*. 2nd ed. Blackwell Scientific Publications, Oxford and Edinburgh.

Schultze, E.-D. & Mooney, H.A. (Eds.) 1994. *Biodiversity and ecosystems function*. Springer, Berlin.

Whitfield, A.K. 1988. The fish community of the Swartvlei estuary and the influence of food availability on resource utilization. *Estuaries*, 11: 160-170.

Whitfield, A.K.; Paterson, A.W.; Bok, A.H. & Hok, H.M. 1994. A comparison of the ichthyofaunas in two permanently open Eastern Cape estuaries. *S. Afr. J. Zool.*, 29: 175-185.

FINAL DISCUSSION AND CONCLUSIONS

A comprehensive understanding of the structure, function and regulation of ecosystems is necessary to solve the world's ever growing environmental problems (Gaedke, 1995). Urgently needed is a strategic approach to predict the development of community structures and the functional responses of ecosystems to different anthropogenic environmental impacts.

The diversity and dynamics of populations cannot be understood, however, unless one simultaneously considers processes at the level of individual populations in concert with those acting over the domain of the entire community. All the populations are embedded in an ecological context, i.e. processes that accrue at the population level permanently change properties of the whole system. These, in turn, impose new constrains back upon the individual populations (Pahl-Wostl, 1993, 1995).

Approaching this idea in practice is made problematic, however, by the extreme complexity of the lagoon which does not allow us to treat fish dynamics in their entirety. Rather, as in all ecological studies, it is necessary to infer information regarding the population based on samples, i.e. to select focus on certain questions given the limitations of the study. Which of the many possible conceptions one chooses to elaborate and examine depends on many factors. In this particular study, choice was strongly influenced by the previous works made in the lagoon, considering the knowledge already established, the ideas and problems that need to be reached, the existing sampling methodology (to enable appropriate comparisons), working conditions and also social and cultural milieu.

There is no consensus on the answer to the most fundamental question in the environmental sciences: how should we deal with the complexity of ecosystems?

Although authors usually acknowledge that their analyses cannot reveal all aspects of nature, strategies on how to deal with its full complexity are typically omitted (Baumann, 1998).

Nevertheless, it is important to take an holistic approach to understanding the structure and functioning of the lagoon. Thus, three main ideas were central to develop and/or to deeply understand in this research: i) the fish diversity and

structure; ii) population dynamics; iii) fish production capacity of the Ria de Aveiro lagoon.

Only a spatial and temporal explicit framework, incorporating what has been learned since then will advance understanding of ecosystem processes and help identify data requirements (Sharp, 1995). In summary, despite the limitations of the field data, this study intended to contribute to the knowledge of the fish assemblage indices to be used together to estimate the fish production and diversity aspects as a whole. This constitutes a pioneer work in the Ria de Aveiro and a valid, indeed essential, research in support of habitat questions of the lagoon.

The knowledge about the lagoon also enhances our comprehension of the non-linear nature of ecosystem behaviour, as well as bridges between the temporal and spatial scales of management on the one hand and ecological systems on the other (Hammer *et al*., 1993; Holmlund & Hammer, 1999).

The global results of this study support the contention that to comprehensively evaluate the fish productive capacity of the lagoon, both fish diversity and dynamics are needed. The evaluation of the productive capacity clearly has a fish production basis of the species that are being produced and could be better understood in the context of the surrounded environment.

Furthermore, the distribution and abundance of fishes found in the Ria de Aveiro are determined by both biotic and abiotic factors. Although these factors are depicted as being independent of one another, in reality there is interaction between a number of them and the fishes which inhabit in it. For example, there are the direct influences of water temperature, salinity, turbidity, dissolved oxygen concentrations, turbidity and depth, and indirect ones of mouth condition, estuarine productivity, fish recruitment, food availability, competition and habitat diversity. However, realising that multiple factors are continually impinging on the lives of fish in estuaries in general (Whitfield, 1996), and in this lagoon in particular, research emphasis should move away from attempting to determine the influence of isolated environmental variables and adopt a more holistic approach.

The results of this study show a dynamic and a variable environment in the Ria de Aveiro, like other transitional water bodies, with significant variations in the

abiotic parameters of the water. These factors identify some of the most diagnostic features of fish assemblages, appearing to be an important influence on the distribution and diversity of the ichthyofauna, with strong seasonal patterns observed. Despite the vulnerability of the system, it was concluded that as with other European estuarine lagoon ecosystems (Alcolado, 1996), the fish community in the Ria de Aveiro exhibits a predictable spatial and temporal pattern of fish biomass and diversity.

The nursery function of lagoons (Rogers *et al*., 1984 *in* Rakocinski *et al*., 1996; Elliott & Hemingway, 2002) and, as shown by temperature patterns in the Ria de Aveiro, seasonal changes appear to have greater importance to the fish assemblage than position within the lagoon. Furthermore, temperature was found to be the most important abiotic factor affecting the abundance (number of fish) distribution of fish assemblage, while salinity was the most important abiotic factor affecting the fish biomass, with temperature also having a major influence.

Despite the degree of long-term changes analysed in this study (industrial, urban or fishing port pressure), it has supported very similar fish communities, with some disappeared species and the entrance of new species, throughout the twentieth century, comprising representatives of various ecological types. Thus, the lagoon appears to be somewhat resilient to anthropogenic variation in a long term variation.

Feeding analysis indicates that fish species are mostly dependent on small benthic and pelagic crustaceans, but detritus seemed to be the most important food source for many fish species in the lagoon. Detritivorous fish taxa are well represented in the Ria de Aveiro, despite the often higher species diversity of carnivorous fishes, the former group are normally dominant in terms of biomass, such as the mullets (*Liza aurata*, *L. ramada* and *L. saliens*).

The low spatial segregation of fish in relation to feeding preference suggests that, in a food-rich lagoon as Ria de Aveiro, the environmental-biological interactions could have a greater effect on fish distribution than do biological interactions.

It is also concluded that fish data have a role in water quality and estuarine management (Whitfield, 1996) but further studies are required to allow the

determination of changes to the integrity of an estuarine resident fish community. There is a need for continuing long-term studies to assess further both the relationship between estuarine and marine survey data and the potential value of estuary data in the management of marine fish stocks.

In a particular case of sympatric species, *Atherina boyeri* and *A. presbyter*, using the tools that were available for this study, and being conscious of some limitations of the methods, this study allowed the separation of distinct ecological behaviour and biological characteristics between species. The abundance and distribution per space and time by length and age, the abiotic preference during the lifespan, the fish and otolith length-weight relationships and the age and growth parameters were markedly distinct in both species.

The general strategy of occupation of *A. boyeri* is based on high densities of occurrence and spatial preference for certain environments, this strategy could reduce interspecific competition by spatial exclusion of the other species (Moreno & Castro, 1995). The use of the lagoon during different periods is a strategy (Moreno & Castro, 1995) that only *A. presbyter* can use that reduces competition between species for food resources. The combination of different strategies of each species gives a wider spectrum of the possibilities of exploitation of the coastal ecosystem food resource, thus reducing interspecific competition.

In essence, the patterns of change in abiotic conditions and also biological features affect the abundance and structure of fish assemblages. The association between high prey abundance and both fish production and diversity appears to exist in the Ria de Aveiro, but more work examining lower trophic levels is needed to understand the links to fish and contrasts with other estuaries and lagoons (McKenna, 2001).

Finally, fish production is found to be of primary interest to fishery managers; fish distribution, species composition and diversity are equally important for assessing the impacts of habitat alteration on fish communities (Jones *et al*., 1996). Nevertheless, it is suggested here that if habitat is altered, changes in fish distribution and species composition are more likely to occur than changes in fish production, since ecosystem productivity may not be affected by localised changes in habitat (Minns *et al*., 1996).

The total annual production of all fish species in the lagoon was calculated at 90.3 tones or 2.1 g m^{-2} $year^{-1}$ in the first year of sampling and 106.7 tones or 2.5 g m^{-2} $year^{-1}$ in the second year. Comparing the fish production estimates with the other in the world it is possible to note that was lower than most ecosystems but was at the same level of some others (Cowley & Whitfield, 2002; Elliott & Hemingway, 2002).

The high production value obtained for sardine, *Sardina pilchardus*, indicated that this seasonal migrant species plays an important role in energy flow within the lagoon and possibly a dominant role in terms of exporting estuarine production (energy) to the nearshore coastal environment.

It is of note that, according to internal reports of Docapesca Portos & Lotas SA., for example, fisheries yields were found to be three times higher than the fish production estimates in a year. It is suggested that this constitutes a serious problem in the fish sector. One of the priorities will be finding a balance between what is ecologically sustainable and what is economically advantageous, that allows fishing without putting in risk the natural resources. Thus, the ecosystem-based management approaches, must rely on both scientific and traditional ecological knowledge.

In particular, management needs to be directed towards a multi-hierarchial, ecosystem-based approach which links the actions of populations to ecosystems properties, including functional diversity and resilience (Schultze & Mooney, 1994; Lawton & Jones, 1995; Carpenter & Turner, 1998).

As final conclusion, as shown throughout the present study, there are general similarities but also differences between the Ria de Aveiro and other estuaries and lagoons in general. This emphasis its individuality not only in the abiotic but especially in the biotic aspects, which enhances the idea that this transitional water body should be each more deeply studied.

This study has provided the first attempt at calculating the fish production capacity of the Ria de Aveiro and the latter highlights the importance of these calculations for the management of this estuarine coastal lagoon that has long been an area of industrialisation and urbanisation, although only recently has the

biological functioning of this ecosystem been studied in relation to anthropogenic threats.

The study also draws attention to the dynamics and complex nature of the lagoon, with abiotic and biotic interactions within the fish community, which highly determine the dynamics of populations, their recruitment, and, eventually, also the equilibrium of the system.

It is also concluded that fish data have a role in water quality and estuarine management (Whitfield, 1996), but that further studies are required to evaluate the state of risk of the system in the near future in relation to the overexploitation of its resources, for achieving an integrated management of the ecosystem, as well as for anticipating the capacity of the area to absorb future demands. It is of particular note that the structure and functioning of estuarine fishes are integral components in the implementation of the European Habitats and Species and the Water framework Directives. Hence in the period when the ecological status of estuaries (Tansitional Waters) has to be defined and quantified against reference conditions, detailed information about estuarine fishes will be central to the management of these areas (Elliott *et al*., 1999).

Future investigations should be directed in order to enable a progressive understanding of the ecosystem functioning directed to food web analysis providing an effective tool for energetic and metabolic activities and trophodynamics, which advance to a deeper insight into the ecosystem functioning as a whole.

GENERAL REFERENCES

Alcolado, P.M. 1996. Controversia sobre la relación entre la diversidad de especies y la estabilidad de las comunidades. *Avicennia,* 4/5: 13-26.

AMRia (Ed.). 2004. AMRia Jornal. Trimestral nº 5, Abril 2004. AMRia. Aveiro.

Arruda, L.M.; Andrade, J.P. & Cunha, M.M. 1988. Abundance, diversity and community structure of the fish population in the Ria de Aveiro (Portugal*). Oceanol. Acta,* 11 (3): 235-240.

Bagenal, T.B. 1978. *Methods for Assessment of Fish Production in Fresh Waters*, 3rd edn. Blackwell, Oxford.

Bamber, R.N. & Henderson, P.A. 1985. Morphological variation in British atherinids, and the status of *Atherina presbyter* Cuvier (Pisces: Atherinidae). *Biology Journal of Limnology Society*, 25: 61-76.

Baumann, M. 1998. The fallacy of the missing middle: physics to fisheries. *Fish Oceanogr.*, 7 (1): 63-65.

Blaber, S.J.M. & Blaber, T.G. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *J. Fish Biol.*, 17: 143-162.

Brown, E.G. & Pierce, G.J. 1998. Monthly variation in the diet of harbour seals in inshore waters along the southeast Shetland (UK) coastline. *Mar. Ecol. Prog. Ser.*, 167: 275-289.

Carpenter, S.R. & Turner, M. 1998. At last: a journal devoted to ecosystem science. *Ecosystems*, 1: 1-5.

Carpenter, S.R.; Kitchel, J.F. & Hodgson, M. 1985. Cascading trophic interactions and lake productivity. *BioScience*, 35: 634-639.

Cowley, P.D. & Whitfield, A.K., 2002. Biomass and production estimates of a fish community in a small South African estuary 61. *J. Fish Biol.* (Supplement A): 74-89.

Creech, S. 1990. The ecology and taxonomy of two European atherinids (Teleostei: Atherinidae). Ph.D. Thesis, University of Wales. College of Cardiff.

Creech, S. 1991. An electrophoretic investigation of populations of *Atherina boyeri* Risso, 1810 and *A. presbyter* Cuvier, 1829 (Teleostei: Atherinidae): genetic evidence in support of the two species. *J. Fish Biol.*, 39: 807-816.

Creech, S. 1992. A multivariate morphometric investigation of *Atherina boyeri* Risso, 1810 and *A. presbyter* Cuvier, 1829 (Teleostei: Atherinidae): morphometric evidence in support of the two species. *J. Fish Biol.*, 41: 341-353.

Department of Fisheries and Oceans (DFO). 1986. The Department of Fisheries and Oceans Policy for the Management of Fish Habitat. Department of Fisheries and Oceans, Ottawa, Ontario.

Elliott, M & Hemingway, K.L. (Eds.). 2002. *Fishes in Estuaries*. Blackwell Science, Oxford.

Elliott, M,; Fernandes, T.F. & de Jonge, V.N. 1999. The impact of recent European Directives on estuarine and coastal science and management. *Aquatic Ecology,* 33: 311-321.

Elliott, M & McLusky, D.S. 2002. The need for definitions in understanding estuaries. *Estuarine, Coastal & Shelf Science*, 55(6): 815-827.

Elliott, M. & Dewailly, F. 1995. The structure and components of European estuarine fish assemblages. *Neth. J. Aquac. Ecol*., 29 (3-4): 397-417.

Elliott, M. & Taylor, C.J.L. 1989. The structure and functioning of an estuarine/marine fish community in the Forth estuary, Scotland. In: Polish Academy of Sciences Institute of Oceanology (Eds.). Proceedings of the 21st European Marine Biologists Symposium Gdansk, 14-19 Sept. 1986. Institute of Oceanology. Warsaw. 227-240 p.

Focant, B.; Rosecchi, E. & Crivelli, A.J. 1999. Attempt at biochemical characterization of sand smelt *Atherina boyeri* Risso, 1810 (Pisces, Atherinidae) populations from the Camargue (Rhône delta, France). *Comp. Biochem. Physiol.*, 122: 261-267.

Focant, B.; Trabelsi, M.; Kartas, F. & Quignard, J.-P. 1992. Charactérization biochemique de trois populations d'*Atherina boyeri* des milieux lagunaires méditerranéens. *Rapp. Comm. Int. Mar. Medit*., 33: 94.

Gaedke, U. 1995. A comparison of whole-community and ecosystem approaches (biomass size distributions, food web analysis, network analysis, simulation models) to study the structure, function and regulation of pelagic food webs. *J. Plankton Res.*, 17 (6): 1273-1305.

Gunter, G. 1969. Fisheries in coastal lagoons. In: UNAM-UNESCO (Eds). Proceedings of the Lagunas Costeras Simposio, 28-30 Nov. 1967. Mem. Simp. Inter. Lagunas Costeras. Mexico, 663-670 p.

Haedrich, R.L. 1983. Estuarine Fishes. In: Ketchum, B. (Ed.), *Estuaries and enclosed seas.* Elsevier. Amsterdam. 183-207 p.

Hammer, M.; Jansson, A.-M. & Jansson, B.-O. 1993. Diversity change and sustainability : implications for fisheries. *Ambio*, 22: 97-105.

Holme, N.A. & McIntyre, A.D. (Eds.) 1984. *Methods for the study of marine benthos*. IBP Handbook no. 16, 2nd. ed. Blackwell Scientific Publications, Oxford.

Holmlund, C.M. & Hammer, M. 1999. Ecosystem services generated by fish populations. *Ecol. Econ.*, 29: 253-268.

JAPA. 1993. *Estudo de impacto ambiental – desassoreamento da Ria de Aveiro, 1ª fase.* Junta Autónoma do Porto de Aveiro. Edição do Porto de Aveiro, Aveiro.

Jones, G.K.; Baker J.L.; Edyvane, K. & Wright, G.J. 1996. Nearshore fish community of the Port River-Baker Inlet Estuary, South Australia. I. Effect of the thermal effluent on the fish

community structure, and distribution and growth of economically important fish species. *Mar. Freshwat. Res.*, 47: 785-99.

Kartas, F. & Trabelsi, M. 1990. Sur le polymorphisme de l'Athérine, *Atherina boyeri* Risso 1810 (Atherinidae) des eaux littorales tunisiennes. *Cybium*, 14: 295-311.

Klossa-Kilia, E.; Prassa, M.; Papasotiropoulos, V.; Alahiotis, S. & Kilias, G. 2002. Mitochondrial DNA diversity in *Atherina boyeri* populations as determined by RFLP analysis of three mtDNA segments. *Heredity*, 89: 363-370.

Lawton, J.H. & Jones, C.G. 1995. Linking species and ecosystems: organisms as ecosystems engineers. In: Jones, C.G. & Lawton, J.H. (Eds.), *Linking Species and Ecosystems*. Chapman and Hall. London. 141-150 p.

Lenanton, R.C.J. & Potter, I.C. 1987. Contribution of estuaries to commercial fisheries in temperate Western Australia and the concept of estuarine dependence. *Estuaries*, 10: 28-35.

Lubchenco, J.; Olson, A.M.; Brubaker, L.B.; Carpenter, S.R.; Holland, M.N.; Hubbell, S.P.; Levin, S.A.; MacMahon, J.A. & Matson, P.A. 1991. The sustainable biosphere initiative: an ecological research agenda. *Ecology*, 72: 371-412.

Marfin, J.-P. 1981. Biologie de L'Atherine : *Atherina boyeri* Risso, 1810 (Poisson Télêostéen) dans trois milieux saumâtre du Roussillon. Thesis (3ème Cycle), Université de Perpignan.

Marfin, J.-P., 1982. Les problèmes lies au polymorphisme de l'espèce *Atherina boyeri* Risso, 1810. *Cybium,* 6 (4): 19-26.

Matthews, W.J. 1998. *Patterns in freshwater fish ecology*. Chapman & Hall, New York.

McKenna, J.E. Jr. 2001. Biological structure and dynamics of littoral fish assemblage in the Easterns Finger Lakes. *Aquat. Ecosyst. Health Manage. Soc.*, 4: 91-115.

Minns, C.K. 1997. Quantifying 'no nets loss' of productivity of fish habitats. *Can. J. Fish. Aquat. Sci.*, 54: 2463-2473.

Minns, C.K. ; Kelso, J.R.M. & Randall, R.G. 1996. Detecting the response of fish to habitat alterations in freshwater ecosystems. *Can. J. Fish. Aquat. Sci.*, 53 (Suppl. 1): 403-414.

Moreno, T. & Castro, J.J. 1995. Community structure of the juvenile of coastal pelagic fish species in the Canary Islands waters. *Sci. Mar*., 59 (3-4): 450-413.

Nobre, A.; Afreixo, J. & Macedo, J. 1915. *A Ria de Aveiro, Relatório oficial do regulamento da Ria de 28 de Dezembro de 1912.* Imprensa Nacional, Lisboa.

Odum, E.P. 1997. *Fundamentos de Ecologia*. Fundação Calouste Gulbenkian, Lisboa.

Osório, B. 1912. Pescas e peixes. Uma nota relativa à pesca e aos peixes da Ria de Aveiro. *Bol. Soc. Geogr. Lisboa,* 30 (4-5): 216-224.

Pahl-Wostl, C. 1993. The hierarchical organisation of the aquatic ecosystem: an outline how reductionism and holism may be reconciled. *Ecol. Modelling*, 66: 81-100.

Pahl-Wostl, C. 1995. *Dynamic nature of ecosystems*. *Chaos and order entwined*. Wiley, Chichester.

Pajuelo, J.G. & Lorenzo, J.M. 2000. Biology of sand smelt, *Atherina presbyter* (Teleostei: Atherinidae), off the Canary Islands (central-east Atlantic). *Environ. Biol. Fish.*, 59: 91-97.

Pombo, L. & Rebelo, J.E. 2000. Ria de Aveiro ictiofauna: diversity in space and time. *Rev. Biol*. (Lisboa), 18: 69-81.

Potter, I.C.; Loneragan, N.R.; Lenanton, R.C.J.; Chrystal, P.J. & Grant, C.J. 1983. Abundance, distribution and age structure of fish populations in a Western Australian estuary. *J. Zool*., 200: 21-50.

Rakocinski, C.F.; Lyczkowski-Shultz, J. & Richardson, S.L. 1996. Ichthyoplankton Assemblage structure in Mississippi Sound as revealed by canonical correspondence analysis. *Estuar. Coast. Shelf Sci.*, 43: 237-257.

Rebelo, J.E. 1992. The ichthyofauna and abiotic hydrological environment of the Ria de Aveiro, Portugal. *Estuaries*, 15 (3): 403-415.

Rebelo, J.E. 1993. A Ictiofauna da Ria de Aveiro e o período lagunar do ciclo de vida do robalo, *Dicentrarchus labrax* LINNAEUS, 1758. Ph.D. Thesis, University of Aveiro.

Reis, A. 1993. *Memórias da Natureza*. Câmara Municipal de Aveiro, Aveiro.

Ricker, W.E. 1971. *Methods for assessment of fish production in Fresh Waters*. 2nd ed. Blackwell Scientific Publications, Oxford and Edinburgh.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada* No. 191.

Rogers, S.G.;Targett, T.E. & Van Sant, S.B. 1984. Fish nursery use in Georgia salt-marsh estuaries: the influence of springtime freshwater conditions. *Trans. Am. Fish. Soc.*, 113: 595-606.

Schultze, E.-D. & Mooney, H.A. (Eds.). 1994. *Biodiversity and ecosystems function*. Springer, Berlin.

Sharp, G.D. 1995. It's about time: new beginnings and old good ideas in fisheries science. *Fish Oceanogr.*, 4: 324-341.

Silva, J.N. 2000. *Aveiro Natural*. Livros Quetzal, Aveiro.

Trabelsi, M.; Faure, E.; Quignard, J.-P.; Boussaïd, M.; Focant, B. & Mâamouri, F. 2002 a. *Atherina punctata* and *Atherina lagunae* (Pisces, Atherinidae), new species in the Mediterranean Sea. 1. Biometric investigations of three Atherinid species. *R.C. Biologies*: 1-9.

Trabelsi, M.; Gilles, A.; Fleury, C.; Mâamouri, F.; Quignard, J.-P. & Faure, E., 2002 b. *Atherina punctata* and *Atherina lagunae* (Pisces, Atherinidae), new species in the Mediterranean Sea. 2. Molecular investigations of three Atherinid species. *R.C. Biologies*: 1-10.

Vallejo, S.M.A. 1982. Development and management of coastal lagoons. Oceanol. Acta. In: Proceedings of International Symposium on coastal lagoons, SCOR/IABO/UNESCO, Bordeaux, France, 8-14 Sep., 1981: 397-401.

Warler, G.; Dando, M. & Burchett, M. 1996. *Sealife. A complete guide to the marine environment.* Pica Press, Netherland and Belgium.

Whitfield, A.K. 1983. Factors influencing the utilization of southern African estuaries by fishes. *S. Afr. J. Sci*., 79: 362-365.

Whitfield, A.K. 1996. A review of factors influencing fish utilization of South African Estuaries. *Trans. Roy. Soc. S. Afr.,* 51: 115-137.